AERONAUTICS

FOURTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1928

INCLUDING TECHNICAL
REPORTS Nos. 283 to 308

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LETTER OF SUBMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the fourteenth annual report of the committee for the fiscal year ended June 30, 1928.

The attention of the Congress is invited to Part V of the committee's report presenting an outline of the present state of aeronautical development. It is encouraging to note from the committee's report that not only has aeronautic progress been at an accelerated rate within recent years but the progress has been greater in 1928 than in any single previous year. The significance of this to the American people and to the advancement of civilization can but faintly be pictured in the light of the amazing development that has characterized the first 25 years of aviation.

This country may well be proud of the contributions it has made to this remarkable development, and I am satisfied that continued support of proven policies will assure the further progress of American aviation. I concur in the committee's opinion that there is need for continuous prosecution of scientific research in order that this progress may continue at the maximum rate.

CALVIN COOLIDGE

THE WHITE HOUSE,
December 6, 1928.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 20, 1928.

MR. PRESIDENT: In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 271, 63d Cong.), I have the honor to transmit herewith the fourteenth annual report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1928.

The year 1928 marks the twenty-fifth anniversary of the first flight of an airplane. It is fitting that the Nation should pause to reflect on the wonderful development of aeronautics in the first quarter of a century of aviation. Improvement in the performance, efficiency, reliability, and safety of aircraft has been made at an accelerated rate within recent years, and it is noteworthy that in this, the twenty-fifth anniversary year, the progress should have been greater than in any previous year.

The National Advisory Committee for Aeronautics has jurisdiction over the scientific study of the fundamental problems of flight and is proud of the contributions it has made to this remarkable record of progress.

The status of the committee as a Government organization and the character of its functions have enabled it to attract the best scientific talent in aeronautics to service on its subcommittees without compensation and this has largely been responsible for the comprehensive character and general effectiveness of its research programs.

Attention is invited to Part V of the committee's report presenting an outline of the present state of aeronautical development. Emphasis is placed upon the need for continuous prosecution of scientific research in order that there may be continuous improvement in the safety and efficiency of aircraft both for military and civil purposes.

Respectfully submitted.

JOSEPH S. AMES,
Chairman.

THE PRESIDENT,
The White House, Washington, D. C.

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DAVID W. TAYLOR, *Vice Chairman*.

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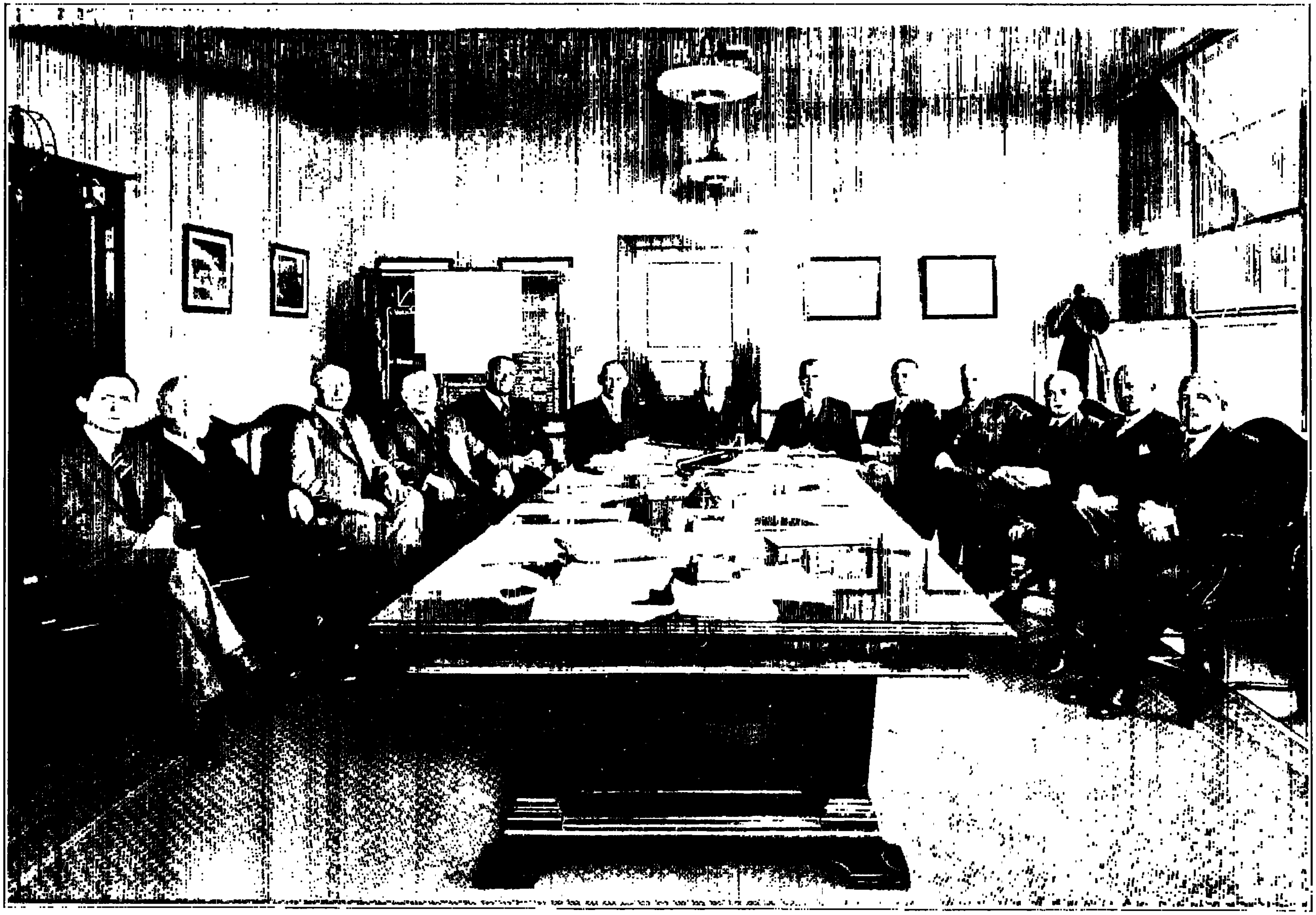

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
SEMIANNUAL MEETING APRIL 18, 1929

Left to right: J. F. VICTORY, Secretary; DR. W. F. DURAND; DR. ORVILLE WRIGHT; DR. G. K. BURGESS; BRIG. GEN. W. E. GILLMORE; MAJ. GEN. J. E. FECHET; DR. JOSEPH S. AMES, Chairman; DR. D. W. TAYLOR, Vice Chairman; CAPT. E. S. LAND; REAR ADMIRAL W. A. MOFFETT; DR. S. W. STRATTON; DR. G. W. LEWIS, Director of Aeronautical Research; DR. CHARLES F. MARVIN. (One member absent - DR. CHARLES G. ABBOT.)

FOURTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 20, 1928.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its fourteenth annual report for the fiscal year 1928.

The year 1928 marks the twenty-fifth anniversary of the first successful flight of an airplane, designed and built by the Wright brothers and flown at Kitty Hawk, N. C., December 17, 1903. The quarter of a century that has intervened has witnessed remarkable progress in the development and use of aircraft for military and civil purposes. During recent years the rate of progress has been accelerated. During the year 1928 greater progress was made than in any single year since the first successful flight of man in a power-driven heavier-than-air flying machine.

This report is submitted in five parts. Part I describes the organization of the committee, states its functions, outlines the facilities available under the committee's direction for the conduct of scientific research in aeronautics, explains the activities and growth of the Office of Aeronautical Intelligence in the collection, analysis, and dissemination of scientific and technical data, and presents a financial report of expenditures during the fiscal year ended June 30, 1928.

In Part II of this report the committee describes its general activities, including the coordination of the study of air-navigation problems, the analysis of aircraft accidents, the consideration of aeronautical inventions and designs, the coordination of aeronautical research in universities, and the cooperation with other governmental agencies and with the industry.

In Part III the committee presents the reports of its standing technical subcommittees on aerodynamics, power plants for aircraft, and materials for aircraft, which include statements of the organization and the functions of each and of the progress of investigations conducted under their general cognizance in laboratories, governmental and private.

In Part IV the committee presents summaries of the Technical Reports published during the past year and enumerates by title the Technical Notes, Technical Memorandums, and Aircraft Circulars issued.

In Part V the committee presents its views as to the present state of aeronautical development with special reference to the technical development of aircraft. The report closes with a summary of the progress made during the past year and of the factors that have contributed to the advancement of American aeronautics.

PART I

ORGANIZATION

FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915. The organic act charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics, for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War and Navy Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air organizations and other branches of the Government, and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

By act of Congress approved July 2, 1926 (Public, No. 446, 69th Cong.), and amended March 3, 1927 (Public, No. 748, 69th Cong.), the committee was given an additional function. This legislation created and specified the functions of an Aeronautical Patents and Design Board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, and provided that upon favorable recommendation of the National Advisory Committee for Aeronautics the Patents and Design Board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

ORGANIZATION OF THE COMMITTEE

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

On December 13, 1927, Maj. Gen. Mason M. Patrick, formerly Chief of the Air Corps, was relieved from membership on his retirement from active service in the Army, and Maj. Gen. James E. Fechet, his successor as Chief of the Air Corps, was, on January 6, 1928, appointed to succeed him as a member of the National Advisory Committee for Aeronautics.

Dr. Charles G. Abbot, Secretary of the Smithsonian Institution, was, under date of June 29, 1928, appointed a member of the committee to fill the vacancy caused by the death in February, 1927, of Dr. Charles D. Walcott.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 20, 1927, and that held on October 18, 1928.

The organization of the committee at the close of the past year was as follows:

Joseph S. Ames, Ph. D., chairman.
David W. Taylor, D. Eng., vice chairman.
Charles G. Abbot, Sc. D.
George K. Burgess, Sc. D.
William F. Durand, Ph. D.
Maj. Gen. James E. Fechet, United States Army.
Brig. Gen. William E. Gillmore, United States Army.
Capt. Emory S. Land, United States Navy.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
S. W. Stratton, Sc. D.
Orville Wright, Sc. D.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held on April 19, 1928, at the committee's headquarters in Washington, and the annual meeting on October 18, 1928, also at the committee's headquarters. At these meetings the general progress in aeronautical research was reviewed and the problems which should be experimentally attacked were discussed. Administrative reports were submitted by the secretary, Mr. John F. Victory, and by the Director of the Office of Aeronautical Intelligence, Dr. Joseph S. Ames.

At both the annual and the semiannual meetings Doctor Ames, as chairman of the executive committee, presented detailed reports of the research work being conducted by the committee at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., and exhibited charts and photographs showing the methods used and the results obtained in the more important investigations.

The election of officers was the concluding feature of the annual meeting. The officers of the committee were reelected for the ensuing year, as follows: Chairman, Dr. Joseph S. Ames; vice chairman, Dr. David W. Taylor; chairman executive committee, Dr. Joseph S. Ames.

THE EXECUTIVE COMMITTEE

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include in addition any member of the Advisory Committee not otherwise a member of the executive committee, but resident in or near Washington, and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
David W. Taylor, D. Eng., vice chairman.
Charles G. Abbot, Sc. D.
George K. Burgess, Sc. D.
Maj. Gen. James E. Fechet, United States Army.
Brig. Gen. William E. Gillmore, United States Army.
Capt. Emory S. Land, United States Navy.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
S. W. Stratton, Sc. D.
Orville Wright, Sc. D.

The executive committee, in accordance with general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities.

On November 25, 1927, the executive committee, on invitation of Admiral Moffett, held a meeting at the naval aircraft factory, Philadelphia, and following the meeting inspected the aircraft carrier, U. S. S. *Saratoga*, which was at the Philadelphia Navy Yard at that time.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the policies and the direction of the activities as approved by the executive committee is vested in the Director of Aeronautical Research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

SUBCOMMITTEES

In order to facilitate the conduct of its work the executive committee has organized nine standing subcommittees, as follows:

Aerodynamics.
Power plants for aircraft.
Materials for aircraft.
Problems of air navigation.
Aircraft accidents.
Aeronautical inventions and designs.
Publications and intelligence.
Personnel, buildings, and equipment.
Governmental relations.

The organization and work of the technical committees on aerodynamics, power plants for aircraft, and materials for aircraft are covered in the reports of those committees in Part III of this report.

The committee on problems of air navigation and the committee on aircraft accidents have recently been established in response to needs which have been gradually increasing during the past few years. A statement as to the organization, functions, and activities of the committee on problems of air navigation is included under the subject of coordination of study of air navigation problems in Part II of this report, while an account of the activities leading to the establishment of the committee on aircraft accidents will be found under the subject of methods of analysis of aircraft accidents, and the work of the committee on aeronautical inventions and designs is included under the subject of the consideration of aeronautical inventions, also in Part II.

Statements of the organization and functions of the administrative committees on publications and intelligence; personnel, buildings, and equipment; and governmental relations, follow:

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

FUNCTIONS

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars of the Committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Prof. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

FUNCTIONS

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.
3. To meet from time to time on the call of the chairman and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Dr. David W. Taylor, vice chairman.
Prof. Charles F. Marvin.
John F. Victory, secretary.

COMMITTEE ON GOVERNMENTAL RELATIONS

FUNCTIONS

1. Relations of the committee with executive departments and other branches of the Government.
2. Governmental relations with civil agencies.

ORGANIZATION

Prof. Charles F. Marvin, chairman.
Dr. David W. Taylor.
John F. Victory, secretary.

QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located in the rear of the eighth wing, third floor, of the Navy Building, Eighteenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy air organizations. This space has been officially assigned for the use of the committee by the Public Buildings Commission. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, at Langley Field, Hampton, Va., and the office of the technical assistant in Europe is located at the American Embassy in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Langley Memorial Aeronautical Laboratory is operated under the direct control of the committee. It is located at Langley Field, Va., on a plot of ground set aside by the War Department for the committee's use. The laboratory was started in 1916 coincident with the establishment of Langley Field.

The laboratory is organized with five divisions, as follows: Aerodynamics division, power plants division, technical service division, flight operations division, and property and clerical division. The administration of the laboratory is under the immediate direction of an engineer in charge, Mr. Henry J. E. Reid, subject to the general supervision of the officers of the committee.

The laboratory consists of seven buildings—a research laboratory building, containing the administrative offices, the technical library, the photographic laboratory, and the headquarters of the aerodynamics, power plants, technical service, and flight operations divisions; two aerodynamical laboratories, one containing a wind tunnel of the standard type and the other a variable-density wind tunnel, each laboratory being complete in itself; two engine dynamometer laboratories of a semipermanent type, both equipped to carry on investigations in connection with power plants for aircraft; an airplane hangar with a repair shop and facilities for taking care of airplanes used in flight research; and a service building, containing an instrument laboratory, drafting room, machine and woodworking shops, and storeroom.

In addition to the above, the laboratory equipment includes a propeller research tunnel in which a velocity of 100 miles per hour may be obtained in a 20-foot air stream.

During the past year the committee has rebuilt the interior structure of the variable-density wind tunnel, which was destroyed by fire on August 1, 1927, the design of the tunnel being changed to an open-throat type. With the experience gained in wind-tunnel design since the construction of the variable-density tunnel in 1922, it was possible to incorporate features which resulted in greater efficiency from the standpoint of power required, ease of operation, accessibility of apparatus, and quality of air flow. The new construction is entirely of metal and all wiring is in conduit, thus eliminating the fire hazard.

A research balance of an entirely new design to insure greater reliability, accuracy, and adaptability for model tests, is being assembled outside of the tunnel for adjustment before its installation. In the meantime, however, drag tests have been made with the auxiliary drag balance which was not destroyed by the fire, and a series of pressure distribution tests with special recording instruments has been made at 20 atmospheres pressure.

In line with the improvement in efficiency of the variable-density tunnel a step was taken toward the utilization of the waste air. A high-speed wind tunnel has been designed and constructed, using the injector principle to create the flow. The waste air from the variable-density tunnel is thus utilized to produce speeds in excess of 1,200 feet per second or 800 miles per hour in the test chamber, which is 12 inches in diameter. Before this tunnel is placed in operation, however, a study will be made to determine the most efficient form of chamber.

To carry on more efficiently the study of ice formation in flight a 6-inch wind tunnel was built with means for refrigerating the air. In this tunnel a study of the conditions for ice formation will be made with a view to determining means for preventing the formation of ice on aircraft.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 168 employees at the close of the fiscal year 1928. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities, who by their helpfulness in many ways have aided the committee materially in its work.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air services, aircraft manufacturers, educational institutions, and others interested, including the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of Government channels.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the Government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially to secure advance information as to work in progress and any technical data not prepared in printed form and which would otherwise not reach this country. John Jay Ide, of New York, has served as the committee's technical assistant in Europe since April, 1921.

The records of the committee show that during the past year copies of technical reports were distributed as follows:

Committee and subcommittee members	1, 398
Langley Memorial Aeronautical Laboratory	1, 984
Paris office of the committee	4, 596
Army Air Corps	2, 254
Naval Air Service, including Marine Corps	4, 062
Manufacturers	10, 328
Educational institutions	6, 784
Bureau of Standards	472
Miscellaneous	38, 785
Total distribution	70, 663

The above figures include the distribution of 20,867 Technical Reports, 15,076 Technical Notes, 19,136 Technical Memorandums, and 8,448 Aircraft Circulars of the National Advisory Committee for Aeronautics. Part IV of this report presents the titles of the publications issued during the past year the distribution of which is included in the foregoing figures. A total of 10,714 written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 49,540 reports were distributed upon request.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1928, as carried in the independent offices appropriation act approved May 16, 1928, was $537,000, under which the committee reports expenditures and obligations during the year amounting to $529,144.54, itemized as follows:

Personal services	$387, 372. 16
Supplies and materials	29, 066. 58
Communication service	1, 008. 16
Travel expenses	12, 610. 09
Transportation of things	1, 244. 50
Furnishing of electricity	5, 636. 26
Rent of office (Paris)	913. 43
Repairs and alterations	21, 225. 27
Special investigations and reports	39, 800. 00
Equipment	30, 268. 09
Expenditures	529, 144. 54
Reserve, "Two Per Cent Club"	7, 665. 33
Unobligated balance	190. 13
Total	537, 000. 00

In addition to the above, the committee had a separate appropriation of $13,000 for printing and binding, of which $12,962.11 was expended.

PART II

GENERAL ACTIVITIES

METHOD OF ANALYSIS OF AIRCRAFT ACCIDENTS

In response to request of Assistant Secretary of the Navy Edward P. Warner, on behalf of the air coordination committee, which consists of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, the National Advisory Committee for Aeronautics established on March 1, 1928, a special committee on the nomenclature, subdivision, and classification of aircraft accidents, for the purpose of preparing a basis for the classification and comparison of aircraft accidents, both civil and military. The request of the air coordination committee was the result of recognition of the difficulty of drawing correct conclusions from efforts to analyze and compare reports on aircraft accidents prepared by different organizations, owing to the different classifications and definitions used.

The membership of the special committee was as follows:

Representatives of the National Advisory Committee for Aeronautics:
- Dr. George K. Burgess, chairman.
- Mr. G. W. Lewis.

Representatives of the Army Air Corps:
- Lieut. D. B. Phillips, United States Army.
- Lieut. J. D. Barker, United States Army.

Representatives of the Bureau of Aeronautics of the Navy:
- Lieut. Commander L. C. Stevens (C. C.), United States Navy.
- Lieut. Charles R. Brown, United States Navy.

Representatives of the Aeronautics Branch of the Department of Commerce:
- Mr. Daniel de R. Scarritt (later succeeded by Mr. Edward P. Howard).
- Mr. Lester T. Bradbury.

In the work of the committee assistance was also rendered by Mr. E. M. Kintz, of the Aeronautics Branch of the Department of Commerce, and Mr. Starr Truscott, of the National Advisory Committee for Aeronautics, who attended most of the meetings, and, in the consideration of the physiological aspects of aviation, by Dr. L. H. Bauer, of the Aeronautics Branch, and Lieut. Commander John R. Poppen (M. C.), United States Navy.

Various methods of analyzing aircraft accidents, including study and classification by (*a*) the immediate causes, (*b*) the underlying causes, (*c*) the nature, and (*d*) the results of the accidents, were considered by the committee, and discussed in detail. A plan devised by Lieutenant Phillips and Lieutenant Brown for the division of the immediate causes of aircraft accidents into four major classes and for the further subdivision of these major classes as seemed desirable, together with proposed definitions of these classes and subdivisions, was submitted for consideration at the first meeting. This plan was carefully considered by the committee at a number of meetings, and modifications were made so as to provide for every type of aircraft accident in the light of the experience of the members in classifying and analyzing accidents in the Government services.

The meeting of May 22, 1928, was attended by Wing Commander T. G. Hetherington, air attaché, British Embassy; Lieut. Yoshitake Miwa, Imperial Japanese Navy, assistant naval attaché, Japanese Embassy; Commander Silvio Scaroni, air attaché, Italian Embassy; Maj. Georges Thenault, assistant military attaché for aeronautics, French Embassy. At this meeting the method of analyzing aircraft accidents according to immediate causes was explained and the value of a uniform system for reporting accidents was discussed. It was suggested that the representatives of the foreign governments consult with the personnel in their governments who were responsible for analyzing and reporting aircraft accidents, regarding the possibility of adopting the proposed method and form. Great interest was expressed and it was the opinion of those present that the adoption of a uniform system would be advantageous. The representatives of the foreign governments were invited to submit comments and suggestions for changes, and it is hoped that this will result in the establishment of a procedure for the international exchange of information regarding aircraft accidents.

In working out the method of analysis, the committee tried to provide a plan which would permit of the careful analysis of aircraft accidents from the point of view of both personnel and matériel problems. The plan permits of the analysis of a particular accident into two or more distinct causes, and makes possible, by the use of percentages, the indication of the relative weight of each cause. The system provides also for the analysis of crashes according to the nature of the accident (take-off accidents, tail spins following engine failure, etc.), the degree of seriousness of personnel injuries, and amount of damage occurring to matériel, and, through the use of a cross-analysis method, allows for the analysis of pilot errors and matériel failures according to the underlying causes of these errors or failures. All these bases of analysis have been combined into a single chart, intended to be used in the study of each individual accident. In this way a method is provided for the analysis of aircraft accidents of different organizations on the same basis, so that the records will be comparable and the preparation of a composite report of all aircraft accidents will be possible. It is believed that if all aircraft accidents occurring in all agencies are classified in the manner recommended, a composite of all the accidents will offer a basis upon which a study may be made and correct conclusions drawn.

At its last meeting, held on July 17, 1928, the committee adopted its final report, presenting the analysis chart and describing in detail the method proposed. This report was approved by the executive committee of the National Advisory Committee for Aeronautics on October 3, 1928, and has been published as Technical Report No. 308 of the Advisory Committee. The method of analysis set forth therein has been adopted for use by the Army Air Corps, the Bureau of Aeronautics of the Navy, and the Aeronautics Branch of the Department of Commerce.

In accordance with recommendation of the special committee, the National Advisory Committee for Aeronautics has reorganized the personnel of the special committee on the nomenclature, subdivision, and classification of aircraft accidents into a standing committee on aircraft accidents for the consideration of questions as to the interpretation of the method of anlaysis, and for the study of information obtained as a result of this analysis.

COORDINATION OF STUDY OF AIR-NAVIGATION PROBLEMS

During the past year the attention of the committee has been invited to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, particularly in the fields of navigation instruments, aerial communications, and meteorological problems. It is the function of the Department of Commerce to provide aids to air navigation, but the coordination of fundamental scientific research on the problems of air navigation falls within the scope of the functions of the National Advisory Committee for Aeronautics as stated in the act establishing the committee, which provides "That it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions."

In order to provide for the coordination of these activities, the committee organized, in August, 1928, a new standing committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation. The membership of this committee is as follows:

Dr. Joseph S. Ames, Johns Hopkins University, chairman.
Dr. L. J. Briggs, Bureau of Standards.

Dr. Edward B. Craft, American Telephone & Telegraph Co.
Brig. Gen. B. D. Foulois, United States Army.
Paul Henderson, National Air Transport (Inc.).
Capt. S. C. Hooper, United States Navy.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
Capt. E. S. Land, the Daniel Guggenheim Fund for the Promotion of Aeronautics.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Col. Charles A. Lindbergh.
Prof. Charles F. Marvin, Weather Bureau.
C. M. Young, Aeronautics Branch, Department of Commerce.

In order that the large and varied field of research on air-navigation problems may be effectively covered, three subcommittees have been organized under the committee on problems of air navigation, as follows:

Subcommittee on problems of communication:

Dr. Edward B. Craft, American Telephone & Telegraph Co., chairman.
Maj. William R. Blair, Signal Corps, United States Army.
Dr. J. H. Dellinger, Bureau of Standards.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
J. L. McQuarrie, International Telephone & Telegraph Co.
C. J. Pannill, Radiomarine Corporation of America.
Lieut. Commander W. J. Ruble, United States Navy.
Eugene Sibley, Aeronautics Branch, Department of Commerce.

Subcommittee on instruments:

Dr. L. J. Briggs, Bureau of Standards, chairman.
Marshall S. Boggs, Aeronautics Branch, Department of Commerce.
Dr. W. G. Brombacher, Bureau of Standards.
Dr. Samuel Burka, Dayton, Ohio.
Charles H. Colvin, Society of Automotive Engineers.
Lieut. A. F. Hegenberger, United States Army, Matériel Division, Air Corps, Wright Field.
Dr. A. W. Hull, General Electric Co.
Carl Keuffel, Keuffel & Esser Co.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. T. C. Lonnquest, United States Navy.
Henry J. E. Reid, National Advisory Committee for Aeronautics.

Subcommittee on meteorological problems:

Prof. Charles F. Marvin, Weather Bureau, chairman.
Thomas H. Chapman, Aeronautics Branch, Department of Commerce.
Dr. W. R. Gregg, Weather Bureau.
Dr. W. J. Humphreys, Weather Bureau.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. F. W. Reichelderfer, United States Navy.
Dr. C. G. Rossby, the Daniel Guggenheim Fund for the Promotion of Aeronautics.
Capt. Bertram J. Sherry, Signal Corps, United States Army.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, a Patents and Design Board was created, and it was provided that upon recommendation of the National Advisory Committee for Aeronautics the board should determine questions as to the use and value to the Government of aeronautical inventions submitted to the Government. By act of Congress approved March 3, 1927, the act of July 2, 1926, was amended in such a manner as to limit the board to the consideration of such cases as were favorably recommended to it by the National Advisory Committee for Aeronautics. This relieved the board of the burden of considering cases which were unfavorably recommended by the committee, but at the same time it made the National Advisory Committee for Aeronautics responsible for the final disapproval of the large majority of the devices submitted as applications for awards.

In order to discharge the duties devolving upon the committee under this legislation, a committee on aeronautical inventions and designs was created, with the following membership:

Dr. D. W. Taylor, chairman.
Dr. George K. Burgess, vice chairman.
Capt. E. S. Land, United States Navy.
Prof. Charles F. Marvin.
J. F. Victory, secretary.

The committee on aeronautical inventions and designs considers such inventions or designs as are deemed by the Director of Aeronautical Research to be worthy of favorable recommendation to the Aeronautical Patents and Design Board or as he desires to bring to the attention of the committee for its action. The Director of Aeronautical Research is authorized to submit any unfavorable recommendations direct to the Aeronautical Patents and Design Board, but any favorable recommendations must be considered and made by the committee on aeronautical inventions and designs.

Under the present procedure careful consideration is given to all inventions and designs submitted. The Aeronautical Patents and Design Board and the National Advisory Committee for Aeronautics are working in harmony and the burden of considering large numbers of inventions is placed so as to reduce the demands on the time of the members of the committee on aeronautical inventions and designs and of the members of the Aeronautical Patents and Design Board to the consideration of submissions which have received competent preliminary examination and are deemed worthy of further consideration.

In the second year of the operation of the Aeronautical Patents and Design Board the committee received about 2,200 letters relating to inventions. Of these, about 1,000 represented wholly new submissions. Of the number submitted for the consideration of the Aeronautical Patents and Design Board—approximately 200—the committee has submitted to the board reports and recommendations in 182 cases, which included favorable recommendation in one case only. The remaining cases were submitted for the direct consideration of the committee and consequently have been disposed of by direct correspondence with the submitters. One case, originally submitted only for the consideration of the committee, was considered to be worthy of consideration by the Aeronautical Patents and Design Board, and was so recommended to the board.

RELATIONS WITH THE AIRCRAFT INDUSTRY

In order to give the representatives of the aircraft industry an opportunity to become familiar with the facilities of the committee's laboratory and the type of investigations conducted there, and to encourage the representatives of the industry to present fundamental problems arising out of commercial aeronautics with a view to their possible incorporation in the committee's research program, the committee in 1926 inaugurated a policy of holding at its laboratory annual conferences between its representatives and the representatives of the industry.

In accordance with this policy, the Third Annual Aircraft Engineering Research Conference was held at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., on May 15, 1928. In addition to the aircraft manufacturers and operators, educational institutions engaged in aeronautical education and aeronautical trade journals were invited to send representatives. The committee was represented by eight of its members, its subcommittees on aerodynamics and power plants for aircraft, and members of its technical staff. Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, presided

At the morning session of the conference the functions and work of the committee were briefly explained, after which the representatives of the industry were conducted on a tour of inspection of the facilities of the laboratory and the investigations in progress. Among the more interesting developments explained or demonstrated were the investigation in flight of airplane maneuverability, the development of a nonspinning wing, the redesigned variable-density wind tunnel, the study in the propeller research tunnel of the cowling and cooling of air-cooled engines, the study of ice formation on aircraft in flight, the development of a 2-stroke cycle gasoline injection engine, the investigation of a 4-stroke cycle oil injection engine, and the development of the improved Roots type supercharger. A small water tunnel recently constructed for the testing of airfoil models at high Reynolds Number and a small demonstration model of a high-speed jet wind tunnel designed to operate on exhaust air from the variable-density wind tunnel were shown in operation.

The afternoon session was devoted to the discussion of the problems of commercial aeronautics, and 30 problems were presented, chiefly by representatives of the industry. Many of these problems were already being investigated by the committee, and the work in progress on these particular investigations was explained by members of the committee's staff. Among the problems discussed were control of airplanes at low speeds; study of wing slots; design factors of propellers; study of load factors for landing gears; effect on airplane performance of changes in tail surface areas and shapes; effect on drag of use of corrugated surface for fuselage and wings; study of downwash; application of study of maneuverability to commercial operation of airplanes; investigation of loads and pressure distribution in commercial flying, especially in rough air; silencing the airplane; heating and ventilation of closed cabin airplanes; comfortable seating of passengers and elimination of vibration; relation between maneuverability and control of an airplane and steadiness of flight in rough air; and landing characteristics as affected by heavy load. All the problems suggested have since been carefully considered by the committee on aerodynamics, and two of them—study of the mutual interference of airplane parts, including the effect of the use of fillets, and study of the effect of the position of the propeller with reference to the wings—have been incorporated in the committee's research program, while others are being given further consideration for investigation in the near future.

At the close of the afternoon session, in accordance with arrangements agreed upon between the Navy and the National Advisory Committee, a number of the members of the conference made flights in the Navy NY training type airplane equipped with Handley-Page automatic slots.

THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

The committee is pleased to note that Capt. Emory S. Land, Construction Corps, United States Navy, a member of the National Advisory Committee for Aeronautics, has become vice president and treasurer of the Daniel Guggenheim Fund for the Promotion of Aeronautics. The fund has continued its useful activities in the field of aeronautics during the past year, and has provided practical and substantial assistance to aviation in its commercial, industrial, and scientific aspects.

The fund has also continued its financial support of educational institutions offering courses in aeronautical engineering, with a view to making available in all sections of the country schools adequately equipped to give instruction along this line. This financial assistance has been rendered to the Massachusetts Institute of Technology, at Cambridge; New York University, in New York City; the University of Michigan, at Ann Arbor; Stanford University, California; and the California Institute of Technology, at Pasadena. The fund also sponsored a conference of representatives of these institutions in Washington on April 27, 1928, for the interchange of ideas relating to educational methods and research to be conducted.

The safe-aircraft competition inaugurated by the fund last year has been continued. This competition was initiated for the purpose of carrying out the primary aim of the fund, the promotion of safety in flying, and has led to efforts on the part of manufacturers and designers to make safer airplanes.

The fund has continued also its study of the problem of flying and landing in fog, and by means of a committee appointed for the purpose has accomplished much toward the coordination of activities along this line.

Another important activity of the fund during the past year was the joint sponsorship with the National Safety Council of a National Congress on Safety in Aviation, which was held in New York City on October 4 and 5, 1928. This conference was attended by representatives of most of the organizations in this country concerned with aeronautics, and problems relating to the promotion of safety in ground installations as well as in flight were discussed.

CONFERENCE OF REPRESENTATIVES OF EDUCATIONAL INSTITUTIONS ACTIVELY ENGAGED IN AERONAUTICAL EDUCATION

In continuation of a policy inaugurated more than a year ago, the Daniel Guggenheim Fund for the Promotion of Aeronautics held, on April 27, 1928, its second conference of representatives of educational institutions actively engaged in aeronautical education, for the purpose of interchanging ideas relative to educational methods, coordinating research work, and developing specialized courses in aeronautical education. The following educational institutions were represented:

Massachusetts Institute of Technology.
New York University.
Stanford University.
California Institute of Technology.
University of Michigan.
University of Toronto.

The Navy Department and the National Advisory Committee for Aeronautics were also represented.

Dr. William F. Durand, a member of the Daniel Guggenheim Fund for the Promotion of Aeronautics and a member and past chairman of the National Advisory Committee for Aeronautics, acted as chairman of the conference. Upon the request of Doctor Durand the committee gave the use of its conference room for the meeting.

The conference considered first the subject of an encyclopedia of aeronautics, and it was believed that there would be a field of usefulness for a work of an encyclopedic character dealing with aerodynamics in relation to the problems of aeronautics and including in particular a critical digest of the experimental and research data which are now available.

The members of the conference exchanged information regarding the equipment of their laboratories and the number of students enrolled in the courses in aeronautical engineering in their respective schools. There was also discussion of the probable ratio during the next few years of the number of aeronautical engineers available to the number demanded by the aeronautical activities of the country.

It was announced at the conference that that would be the last of such meetings under the auspices of the Guggenheim Fund, and that the coordination of aeronautical research in educational institutions would in the future be undertaken by a subcommittee on aeronautical research in universities, which was being organized by the National Advisory Committee for Aeronautics as a subcommittee of its committee on aerodynamics.

For the purpose of circulating research programs and other information among the institutions represented at the conference, Prof. E. P. Lesley, of Stanford University, was appointed secretary. The programs of research of the various schools were later submitted to the National Advisory Committee for Aeronautics and referred to the subcommittee on aeronautical research in universities, which has since been organized. These programs may be found under the report of that subcommittee in Part III of this report.

COORDINATION OF AERONAUTICAL RESEARCH IN UNIVERSITIES

In response to suggestion that the National Advisory Committee for Aeronautics undertake the coordination of the scientific research in aeronautics being conducted by a number of educational institutions in connection with their courses in aeronautical engineering, the committee organized, in September, 1928, under the committee on aerodynamics, a standing subcommittee on aeronautical research in universities, with Prof. Charles F. Marvin as chairman. The purposes of this subcommittee are to coordinate the research work undertaken by the various institutions of learning and to aid in improving the courses in aeronautical engineering and in promoting the study of aeronautics and meteorology. This subcommittee will continue the work initiated two years ago by the Daniel Guggenheim Fund for the Promotion of Aeronautics and carried out by means of two conferences held under the auspices of the fund.

The subcommittee on aeronautical research in universities has been organized with a representative from each of the aeronautics departments of the Californis Institute of Technology, the Massachusetts Institute of Technology, the University of Michigan, New York University, and Stanford University. A complete statement of the organization and functions of this subcommittee will be found under the report of the committee on aerodynamics in Part III of this report.

COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

For the past several years the most cordial relations have been maintained between this committee and the Aeronautical Research Committee of Great Britain. These relations have been strengthened during the past year as a result of the visit to England in 1927 of Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, and by the visit in 1928 of Mr. George W. Lewis, the committee's director of aeronautical research. These visits have led to additional cooperation between the two committees in the study of several important problems of aeronautical research.

For a number of years the two committees have been engaged in the conduct of comparative tests of models in British and American wind tunnels with a view to the standardization of wind-tunnel results. Information obtained from these tests has been published from time to time by both this committee and the British committee.

In these comparative tests, the results obtained in the committee's variable-density wind tunnel at Langley Field were of particular value because they furnished important information regarding the effect of scale in model tests. As a result of these tests and of Doctor Ames's visit to England, the British committee decided to construct a variable-density wind tunnel at the National Physical Laboratory, and this committee has cooperated by supplying the British committee with information regarding the design of the variable-density wind tunnel at Langley Field and experience in its operation.

Comparative tests by the two committees have also been conducted on a metal propeller model, first in an open-jet wind tunnel at Stanford University and then in a closed-type wind tunnel at the National Physical Laboratory, and it is of interest to note that when correction was made in accordance with the Prandtl theory for the wall effect in the closed tunnel the results of the two series of tests showed excellent agreement.

An agreement has been reached for the exchange by the two committees of flight-test instruments, each committee conducting tests of instruments designed and built by the other. Definite arrangements for such an exchange are now being made, and it is hoped that these tests will prove mutually helpful to the two committees in the development of the best possible instruments for flight research.

COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army and Navy air organizations serving on the main committee and the frequent personal contact on the subcommittees of their chief subordinates who have to do with technical matters in aeronautics there has been accomplished in fact not only a coordination of aeronautical research, which is the major function of the committee, but also a coordination of experimental engineering activities of the services and an exchange of first-hand information, comment, and suggestions that have had beneficial effects in both services. The needs of each service in the field of aeronautical research are discussed and agreements invariably reached that promote the public interests. The cordial relations that usually follow from frequent personal contact are supplemented by the technical information service of the committee's Office of Aeronautical Intelligence, which makes available the latest scientific data and technical information secured from all parts of the world. Although there is a healthy rivalry between the Army and Navy air organizations, there is at the same time a spirit of cooperation and a mutual understanding of each other's problems that serve to prevent unnecessary duplication in technical developments in aeronautics.

Much of the fundamental research work of the committee has grown out of requests received from the Army and Navy for the study by the committee of particular problems encountered in the services, and in connection with this work the committee desires to give special recognition to the splendid spirit of cooperation of the two services with the committee. Each service has placed at the disposal of the committee airplanes and engines required for research purposes, and has otherwise aided in every practical way in the conduct of scientific investigations by the committee. Without this cooperation the committee could not have prosecuted successfully many of its investigations that have made for progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads Naval Air Station.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the technical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however, the Army Air Corps or the Naval Bureau of Aeronautics desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

FOR THE AIR CORPS OF THE ARMY

Investigation of the flat spin of the Douglas O–2 airplane.
Full-scale investigation of different wings on the Sperry messenger airplane.
Investigation of the behavior of an airplane in landing and in taking off.
Investigation of pressure distribution and accelerations in pursuit-type airplane.
Acceleration readings on the PW–9 airplane.
Wind-tunnel investigation of biplane cellules.
Investigation of pressure distribution on observation-type airplane.
Study of mutual interference of propeller and fuselage with geared engine.
Study of comparative performance with various types of superchargers.
Tests in special wind tunnel and in flight of atmospheric conditions causing ice formation.
Determination of moment coefficients and hinge moment coefficients for different tail surfaces.
Determination of aileron hinge moments versus rolling moments for various types of ailerons and wings.
Investigation of wing flutter.

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

Investigation of pressure distribution on vertical tail surfaces fitted with balanced rudders.
Investigation of methods of improving wing characteristics by control of the boundary layer.
Development of a solid-injection type of aeronautical engine.
Investigation of NY training airplane with Handley Page automatic slot.
Determination of radii of gyration of O2U–1 airplane.

Investigation of windshields and fairings for protection from air currents.
Investigation of comparative aerodynamic resistance of riveted and bolted construction.
Investigation of parasite resistance and propeller efficiencies of PB-2.
Investigation of method of improvement in visibility in an airplane.
Investigation of maximum tail loads in dives.
Investigation of the forces on seaplane floats under landing conditions.
Investigation of water pressure distribution on seaplane hulls.
Study of design factors for metal propellers.
Investigation of application of compression ignition to air-cooled engine cylinders.
Investigation of flight path characteristics.
Effect of varying the aspect ratio and area of wings on performance of fighter airplane with supercharged air-cooled engine.
Investigation of aerodynamic loads on the U. S. S. *Los Angeles.*
Investigation of autorotation.
Investigation of spoiler aileron control.
Development of aircraft engine supercharger.
Effect of various forms of cowling on performance and engine operation of fighter airplane with supercharged air-cooled engine.
Prevention of ice formation in flight.
Comparative tests of rubber and Oleo type landing gears.
Investigation of the drag of a wing radiator.
Wind-tunnel tests of racing wing sections.

AMERICAN AIRSHIP DEVELOPMENT

In February, 1928, the question of the Nation's policy regarding the development of rigid airships and the creation of an American rigid-airship industry was pending before the Congress of the United States. There was a difference of opinion at the time as to whether appropriations should be made for the construction for the naval service of rigid airships. On February 16, 1928, Senator Hiram Bingham, of Connecticut, addressed a letter to the committee stating that he would appreciate having the committee answer from the information available the following questions regarding the development and operation of large rigid airships:

1. In the opinion of the National Advisory Committee for Aeronautics, does the present state of the art of constructing and operating large rigid airships justify the belief that such airships can be constructed and operated successfully?

2. What, in the opinion of the committee, are the most practical steps that can be taken at this time to encourage the development of an airship industry in the United States looking toward the promotion of commercial air navigation by rigid airships?

Under date of March 1, 1928, the committee replied to Senator Bingham as follows:

Hon. HIRAM BINGHAM,
United States Senate, Washington, D. C.

DEAR SENATOR BINGHAM: Your letter dated February 16, 1928, making certain inquiries as to the opinion of the National Advisory Committee for Aeronautics with reference to the construction and operation of rigid airships and the development of an airship industry in the United States, was considered at a meeting of the executive committee held March 1, 1928, and the following resolutions were adopted:

Resolved, That it is the opinion of the National Advisory Committee for Aeronautics that the present state of the art of constructing and operating large rigid airships has progressed to the point where we are justified in believing that large rigid airships can be constructed and operated successfully.

Resolved further, That it is the opinion of the National Advisory Committee for Aeronautics that the most practical step to be taken at the present time to encourage the development of an airship industry in the United States is to begin the construction of the airships authorized under the 5-year aircraft building program. The construction of these airships will foster the development of an airship industry, and this, with the knowledge to be acquired from experience in the operation of airships, will be necessary in order to enable the United States to meet the needs for commercial airship construction and operation when they arise.

The committee appends hereto a memorandum entitled "The Present Status of the Development of Rigid Airships in the United States," which states the facts on which its opinion is based.

Sincerely yours,

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman.*

The memorandum inclosed with the committee's letter follows:

THE PRESENT STATUS OF THE DEVELOPMENT OF RIGID AIRSHIPS IN THE UNITED STATES

CONSTRUCTION

No rigid airship has been built in this country since the *Shenandoah* was completed in 1923, but theoretical studies, research and practical tests have continued so that ultimately additional rigid airships might be designed and built in the United States. As a result, the United States is to-day as fully abreast of rigid airship development as could be expected without actual construction since 1923.

The *Shenandoah* was a remodeled copy of a 1916 German design and, when completed, was recognized as an admirable first American effort rather than as a modern rigid airship. The necessity for providing suitable materials for the *Shenandoah* led to the further development of aluminum alloys and brought to the United States expert talent who knew how to manufacture gas cells. Additional technical experts were brought to this country who were familiar with rigid airship fabrication, erection, and operation. Original thought and effort were expended along various lines connected with theoretical design, with the result that in spite of meager information as to the prototype the design of the *Shenandoah* was placed upon a sound basis. A special subcommittee of the National Advisory Committee for Aeronautics checked the design and found it reasonable. Recent information confirms this opinion.

The *Shenandoah* was operated successfully by the Navy for two years. Her operation proved the practicability of mooring masts ashore and afloat. She made a number of notable flights, including one of 9,000 miles to the west coast and return, during which she was based entirely on mooring masts for 21 days. A noteworthy flight resulted from a breakaway from the mooring mast. During this she weathered a gale in a badly damaged condition. The fact that she was finally caught in an unusually severe storm and succumbed to it is no reason to condemn her as an airship—much less to condemn airships in general. Engineering history is full of instances where final success has been reached only through lessons learned in early attempts.

The acquirement in 1924 of the *Los Angeles*, as an example of modern German airship construction, was an important step in airship development in the United States. With the *Los Angeles* there came much information about questions hitherto obscure. Shortly after the *Los Angeles* arrived there was brought to this country a group of the most experienced rigid airship engineers. They still remain and represent the quarter of a century of Germany's experience in airship design and construction.

The United States began its experience with rigid airships nearly 10 years ago, and the present "state of the art" may be summarized as follows: One rigid airship was built and operated successfully; another was acquired and is still being operated successfully; much thought and effort have been applied to engineering problems connected with airships; technical personnel familiar with airship matters are available, including those self-trained in the United States; the technical knowledge and experience available in the United States for the design and construction of rigid airships is ample; satisfactory materials are available, notable examples being aluminum alloys, steel wire, cotton cloths, gas-cell materials of various kinds, engines, and power plant equipment, including water-recovery apparatus; promising development of oil-burning engines is under way; and helium, available only in the United States, gives to American airships a unique measure of safety.

From a technical standpoint it is believed the United States is prepared to design and build rigid airships to any required degree of engineering exactitude. American ingenuity and production methods applied to airship construction will cheapen their cost and offset the present high cost differential between American and foreign airships.

OPERATION

The successful operation of rigid airships depends on two factors (*a*) trained personnel and (*b*) facilities available, which include weather information service. Operation is also a matter of experience. Although our experience is not as wide as that possessed by the Germans or English, it is more recent.

The American personnel engaged in rigid airship operation is the equal of any. They have been largely self-taught, but the foundation of the training was sound and embodied the best of German and British experiences, adapted to American conditions and to helium operation. As only one rigid airship has been in operation at a time, competitive effort has not been possible. Development would be faster if more rigid airships were available. The large cost of rigid airships and the fact that only one is now available forced a cautious, conservative scheme of operation which, though sound, has not as yet allowed the technique of rigid airship operation to develop to the full extent of its possibilities. This situation will correct itself when more airships and better facilities are available.

The facilities for the operation of rigid airships in the United States are not the best and additional facilities are needed. There are only two large sheds—at Lakehurst and at Scott Field. The former in particular is poorly located from a meteorological standpoint. The shortage of helium and meager facilities for its transportation and storage have retarded the operation of rigid airships at intervals. Several mooring masts have been erected at strategic points, but the masts remote from the shed base have been used only once.

Arrangements and mechanical appliances for landing airships and handling them on the ground, and in or out of sheds, are being improved with experience. As a result we should be prepared to handle the larger airships now contemplated with no more difficulty, and perhaps with less difficulty, than airships of the *Los Angeles* size. There has been gratifying progress in developing the floating mast, the fixed stub mast, the mobile stub mast, mechanically operated docking trolleys, cars for supporting airships while moving in and out of sheds, artificial superheat device, remote control for hauling down winches and the deck landing platform.

The operation of airships, like airplanes, is influenced by weather conditions and will be facilitated by improved weather information service. A new system for the collection and distribution of weather reports has recently been worked out by the Weather Bureau in cooperation with the telegraph companies. This will much facilitate the prompt furnishing of aerological information so necessary for the safe navigation of the air.

FOREIGN DEVELOPMENT

No survey of rigid airship development would be complete without a résumé of what is being done by other nations.

Germany, the original home of the rigid airship, and where it finds most enthusiastic support, is just completing a 3,650,000 cubic foot airship, funds for which were raised largely by popular subscription. It is proposed that this airship, after making demonstration flights, including one to the United States, will be used to start a commercial line between Spain and South America. The design is a modern and enlarged copy of the *Los Angeles*. This airship will carry a large portion of its fuel in gaseous form. This permits an important increase in cruising range. This development is being watched with interest and a combination of helium and a fuel gas offers attractive possibilities without much greater risk than with helium alone and gasoline.

Great Britain, after abandoning airships for the sake of economy in 1919 and after being confirmed in her antiairship convictions by the *R-38* disaster in 1921, executed an about face in 1923 and resumed the construction of rigid airships. Great Britain now believes airships will play an important rôle in linking up her outlying possessions.

Two rigid airships of 5,000,000 cubic foot volume and using hydrogen are nearly completed. One of these is being built by the Air Ministry, the other by the Airship Guarantee Co., a subsidiary of Vickers (Ltd.). From all information available the designs appear to be on a sound basis and there is no reason to doubt their success. The Airship Guarantee Co. uses a novel and ingenious type of girder which promises to simplify and cheapen the structural parts of an airship. The Air Ministry airship will use considerable alloy steel. Oil-burning engines are proposed for both airships, but they are not yet sufficiently developed to be pronounced satisfactory. Each airship is fitted with accommodations for about 100 passengers and both are intended for quasi subsidized commercial service to India.

Great Britain has five shed berths for large rigid airships. A new shed has been erected in India and one shed in England is being enlarged. Mooring masts have been built in England, India, and Egypt. Other masts are contemplated in Canada, Australia, and South Africa.

At least one of these British airships is expected to visit the United States during the summer of 1928.

France has several sheds suitable for large rigid airships, but probably for reasons of economy has not built such craft. Designs are available and she contents herself with trying to keep abreast of development without building or operation.

Italy still operates the small rigid airship *Esperia* delivered to her in 1922 by Germany. Italy's own airship efforts, however, are concentrated on developing the semirigid type, which satisfies her geographic requirements. An enlargement of the *Norge* type is under construction. In her chosen field of moderate sized airships Italy has developed a superior technique of design, construction, and operation.

The answer of the committee to Senator Bingham's inquiry was published in the Congressional Record of March 9, 1928. Subsequently the Congress made appropriation for the construction of two large rigid airships, and construction has actually begun on the contracts executed by the Navy Department with the Goodyear-Zeppelin Corporation, Akron, Ohio. This step marks the beginning of a rigid-airship industry in the United States, and without doubt will lead to material progress in the design, construction, and use of rigid airships.

PART III

REPORTS OF TECHNICAL COMMITTEES

REPORT OF COMMITTEE ON AERODYNAMICS

ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. David W. Taylor, chairman.
Capt. H. C. Richardson (C. C.), United States Navy, vice chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lieut. W. S. Diehl (C. C.), United States Navy.
Maj. C. W. Howard, United States Army, matériel division, Air Corps, Wright Field.
Prof. Alexander Kelmin, Department of Commerce.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Maj. Leslie MacDill, United States Army, matériel division, Air Corps, Wright Field.
Prof. Charles F. Marvin, Weather Bureau.
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.
Dr. A. F. Zahm, construction department, Washington Navy Yard.

FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments, in progress or proposed.
4. To direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics, by reason of the representation of the various organizations interested in aeronautics, is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, duplication of effort being thus prevented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aerodynamic research. The committee keeps the research workers in this country supplied with information on European progress in aerodynamics by means of a foreign representative who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field and of a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at Wright Field, and the Bureau of Standards are reported to the committee on aerodynamics.

SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in close touch with the latest developments in the field of airship design and construction, and that research on lighter-than-air craft may be fostered and encouraged, a subcommittee on airships has been organized under the committee on aerodynamics, the membership of which is as follows:

Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics, chairman.
Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.
Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.
Commander Garland Fulton, United States Navy.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Capt. William B. Mayer, United States Army, matériel division, Air Corps, Wright Field.
R. H. Upson, Aeromarine Klemm Corporation.

During the past year the results of investigations by the technical staff of the National Advisory Committee on the effect of length-diameter ratio on airship models of Goodyear-Zeppelin design, carried on in the variable-density wind tunnel and on the pressure distribution over the envelope and control surfaces of the U. S. S. *Los Angeles*, conducted at Lakehurst in cooperation with the Bureau of Aeronautics of the Navy, have been considered by the airships subcommittee. Reports on the *Los Angeles* tests will be published by the National Advisory Committee.

The airships subcommittee recommended for approval the study of airship forms, and especially of airship appendages, in the variable-density wind tunnel at Langley Field, and this problem was added to the committee's program. It is planned to include in this investigation the testing of two models with a number of different arrangements of power cars and fins.

A recent meeting of the subcommittee was to a large extent devoted to a discussion of the structure of the atmosphere and its effect on airship operation. Representatives of the Weather Bureau, the Signal Corps of the Army, and the Bureau of Aeronautics, who are in close touch with the study of wind gusts, were invited to the meeting. Some of the specific questions discussed were abrupt changes in wind velocity and the stresses set up in airships by such changes, instruments, and methods for the study of wind direction and velocity, and the importance of obtaining exact data on the variation and velocity of air flow. Consideration was given to the need of attacking these problems by the study of the atmosphere at ground level, at the greatest height at which a support can be placed, and at a great height by some means not yet fully defined. A careful study of the existing knowledge of the subject and of the work already done has been made for the subcommittee by a representative of the Weather Bureau under the direction of Doctor Gregg. With the organization of the recently established subcommittee on meteorological problems of the committee on problems of air navigation, it is hoped that these problems can be considered in cooperation with that subcommittee.

SUBCOMMITTEE ON AERONAUTICAL RESEARCH IN UNIVERSITIES

In order to coordinate the aerodynamic research work undertaken by the various institutions of learning and to aid in improving the courses in aeronautical engineering and in promoting the study of aeronautics, a subcommittee on aeronautical research in universities was organized in September, 1928, with the following membership:

Prof. Charles F. Marvin, Weather Bureau, chairman.
Prof. C. H. Chatfield, Massachusetts Institute of Technology.
Prof. Alexander Klemin, New York University.
Prof. E. P. Lesley, Stanford University.
Mr. G. W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Prof. Clark B. Millikan, California Institute of Technology.
Prof. F. W. Pawlowski, University of Michigan.

The functions of the subcommittee on aeronautical research in universities are as follows.

1. To consider aeronautical problems with a view to the initiation and conduct of aeronautical research by educational institutions; and in connection therewith to prepare programs of suggested lines of research intended to supplement existing research programs and to develop and train personnel for the conduct of scientific research in aeronautics along original lines.

2. To seek through interchange of ideas to improve the courses in aeronautical engineering and to promote the study of aeronautics and aerology in educational institutions.

3. To meet from time to time on call of the chairman and to report its actions and recommendations to the committee on aerodynamics.

At a conference of representatives of educational institutions engaged in the teaching of aeronautical engineering held in Washington on April 27, 1928, under the auspices of the Daniel Guggenheim Fund for the Promotion of Aeronautics, at which conference the National Advisory Committee for Aeronautics, as well as the Navy Department, was represented, arrangements were made for the circulation by Prof. E. P. Lesley of research programs among the institutions represented at the conference, prior to the organization of the subcommittee on aeronautical research in universities. Through the courtesy of the Guggenheim Fund and of Professor Lesley copies of these programs have been forwarded to the National Advisory Committee for Aeronautics and referred to the subcommittee on aeronautical research in universities. The principal items of aerodynamic investigation included in the research programs received from the educational institutions in the United States are as follows:

Massachusetts Institute of Technology.—1. Construction and calibration of new 5-foot wind tunnel of the Venturi type, with closed experimental chamber.

2. Continuation of investigations of mutual interference effects of airplane propellers and other parts of the airplane. This is to include the effects of radical changes in fuselage form and location, the effect of radial engine cylinders with different types of cowling, the effect of different propellers on performance, and the effect of nacelles in multi-engine airplanes.

3. Measurements of flow around model airplane as influenced by the propeller, particularly in the region near the tail.

4. Possible experimental determination of actual air flow near the blades of the propeller as opposed to the mean air flow.

5. Pressure distribution on tail with slip stream.

6. Design and construction of a new type of rib testing machine.

7. Development of a unit instrument to facilitate airplane performance testing.

New York University.—1. Development of methods of measurement, calculation, and correction for tests in connection with the Guggenheim safe-aircraft competition.

2. Continuation of studies in the problem of longitudinal stability and control at the stall.

3. Continuation of work on the aerodynamic resistance of air-cooled engines with various types of cowling.

Stanford University.—1. An experimental investigation of the performance characteristics of a series of five metal model propellers in a free wind stream and in combination with a model of a VE–7 airplane.

2. An experimental investigation of the rotational velocity of the slip stream of air propellers. It is planned first to determine the rotation in the slip stream of a series of United States Navy standard model propellers and then to investigate the effect of straightening vanes upon the power absorbed and efficiency.

3. An experimental and theoretical investigation of the causes of discontinuous air flow. It is desired to formulate criteria which will enable the prediction of the departure of smooth flow from the surface of an airfoil or streamline body.

4. An experimental investigation of the induced drag of high aspect ratio airfoils. It is intended to test airfoils having aspect ratios from 6 to 15 and to compare the results with the predictions of the Lanchester-Prandtl theory.

5. An experimental investigation of the profile drag of certain airfoils. A special form of airfoil has been devised for which it appears that the induced drag should be zero and therefore that the profile drag may be measured directly by a balance. A metal airfoil (Clark Y section) has been constructed. If the results are as expected, the investigation will be extended to other forms.

California Institute of Technology.—1. Theoretical investigations in boundary layer, heat conduction, and other aerodynamical subjects.

2. Full-scale construction and free-flight testing of a new model of the Merrill type stagger-decalage biplane.

3. Installation and calibration of apparatus in the Daniel Guggenheim Laboratory.

University of Michigan.—1. Research into the economic and engineering aspects of air transportation.

2. Research in solution of St. Venant problem for typical propeller blade sections.

3. Design, construction, installation, and calibration of apparata in the new wind tunnel.

UNIVERSITY OF TORONTO.—Through the courtesy of the Guggenheim Fund and of Prof. J. H. Parkin, of the University of Toronto, the committee has received the following information regarding aerodynamic research work at that university:

Researches completed and ready for printing.—1. Air flow over airfoils: Yawmeter study of air flow in neighborhood of wing tips for R. A. F. 15, U. S. A. 27, and Göttingen 387 airfoils.

2. Effects of mutual interference between wings and fuselage for three typical fuselages and their wing sections (R. A. F. 15, U. S. A. 27, and Göttingen 387) in typical monoplane and biplane combinations.

3. Report of international trials on airship models.

Researches in progress.—1. Stability characteristics of flying boat: Determination of aerodynamic characteristics and rotary derivatives of single-engine pusher biplane flying boat.

2. Undercarriage drag: Measurements of drag of wheel, ski, and float undercarriages on typical commercial monoplane and biplane.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ATMOSPHERIC WIND TUNNEL—*Aerodynamic safety.*—The importance of safety in airplane flight is increasing with the present rapid growth of civil aviation. Airplane structures and engines are now highly reliable, but modern airplanes still possess certain aerodynamic characteristics to which many of the accidents occurring in flight must be attributed.

Recognizing the vital need of greater aerodynamic safety, the National Advisory Committee for Aeronautics for the past two years has been concentrating the efforts of its atmospheric wind-tunnel staff on an investigation of the aerodynamic factors that produce dangerous conditions in flight, with a view to remedying these conditions. As a guide in this work the requirements of the type of airplane which must be inherently safe to the greatest degree are being kept in mind. This is the type, as yet undeveloped in practice, which might be flown safely by the unskilled owner-pilot who now drives his own motor car. In general, the information obtained from the study of this extreme type will also make possible the solution of the less difficult safety problems of commercial and military airplanes.

The present investigation is concerned chiefly with the factors affecting the landing, stability, controllability, and spinning of airplanes. In addition, the aerodynamic aspects of dangerous ice formation on airplane parts when in flight are being studied.

Landing.—Bringing an airplane safely and comfortably to the ground is a precise operation requiring considerable skill, particularly when the landing is forced. Because of the necessary frequency of landings this problem is considered to be of first importance. In most airplanes the lift reaches a maximum quite sharply and then decreases rapidly when the control column is pulled back too far. The result of such a maneuver is a rapid drop of the airplane and frequently a crash. It is apparent that a wing having a maximum lift extending over several degrees of angle of attack would materially reduce this danger.

During the past year a new airfoil profile, the N. A. C. A. 84, has been developed by the committee, and wind-tunnel tests have shown that after reaching its maximum the lift remains practically constant over a range of 9°. However, this is but a first step toward reducing the skill required in landing, and further tests are to be made on tapered wings and biplane combinations, together with a study of the possibilities of landing automatically.

Stability.—An airplane for the private flyer should have a high degree of stability. Not only should it be able to fly itself in smooth air, but it should also be capable of returning, with controls released, to level flight when disturbed therefrom by an inadvertent act of the pilot or by a gust. It is, of course, imperative that under no conditions should a rapid loss of altitude occur against the desire of the pilot, for such a possibility places the airplane and its occupants in imminent danger when near the ground. A large number of present day accidents are due to just such a loss of altitude resulting from a sharp side slip or dive or both, following the stalling of the airplane. The side slip is due to the tendency of curved lifting surfaces to roll or autorotate when stalled, a characteristic that has been called "rotary instability." The diving tendency is due chiefly to the relatively rapid rearward travel of the center of pressure as the airplane becomes stalled.

The tests on the N. A. C. A. 84 airfoil have indicated that wings with flat-top lift curves may be expected to have but a small range of "rotary instability" and small diving tendencies when stalled. This part of the investigation will be continued in order to determine the factors affecting the stalled side slip and dive for the purpose of removing the causes.

Controllability.—The privately owned airplane should be capable of executing very gentle maneuvers only, and hence its controllability should be judiciously limited. However, the controls must be effective under all possible conditions of flight. The orthodox plain flap aileron becomes relatively ineffective beyond the angle of maximum lift, and lateral control is thereby seriously impaired. The British have within recent years developed the Frise and the Handley-Page ailerons, both of which are conceded to show marked improvement in lateral control in stalled flight.

However, it can not be emphasized too strongly that controllability is, at best, only a cure for the dangers of instability, whereas the proper degree of stability is positive prevention of these dangers.

During the past year, preliminary wind-tunnel tests have been made on six widely different types of lateral control devices, including the plain flap aileron for comparison. The results of these tests are now being prepared for publication.

Spinning.—The spinning of an airplane is largely dependent on the phenomenon of autorotation, previously mentioned, which may at present be considered the most important single factor affecting the safety of airplanes. It is therefore imperative that autorotation be investigated completely.

This task was undertaken two years ago by the committee, and a comprehensive test program is now in progress. The program includes force, pressure distribution, and autorotation torque tests on a wide variety of monoplane and biplane wing models covering practically all the wing systems in modern use. A large range of angles of attack is covered in each test. The force tests have been completed and two papers have been written presenting the results. The pressure distribution tests are now under way. The autorotation torque tests, which will be made on a specially designed and constructed dynamometer, will be started in the near future.

The primary object of this part of the investigation is to obtain information for the development of nonspinning wings or wing systems. In addition a large amount of detailed reference data will be made available for publication.

Ice formation.—During the past year or two many scheduled or long distance flights have been interrupted, sometimes disastrously, by the formation of a heavy layer of ice on the exposed parts of the airplane. The effect of this layer is to decrease the lift and increase the drag as well as to load the airplane heavily, and a dangerous condition results.

In order to study this phenomenon in the laboratory, a small wind tunnel having a 6-inch-diameter jet and equipped with apparatus for refrigerating the air has been built and is now in operation. In preliminary tests ice formations which resemble those observed in flight have been obtained on round wires and on strut and airfoil sections.

These tests will be extended for the purpose of determining means for the prevention or the avoidance of ice formation. Several possible methods are under consideration.

Aerodynamic efficiency.—Airplane efficiency may be increased by decreasing the size of the wing or wings, provided the maximum lift coefficient can be increased. Two independent methods of obtaining this increase are the moving of trailing edge flaps downward, and boundary layer control by means of pressure or suction slots. For a large increase, the two methods may be used together. The Handley-Page slot-and-flag device is of the latter type.

Preliminary tests on boundary layer control were made last year and the results have been published this year. The method is still chiefly of academic interest on account of the practical difficulty of providing an independent source of pressure or suction in flight.

Tests have also been made on several types of trailing edge flaps, the results of which are being prepared for publication.

A test program has been planned, which includes tests on combinations of slots and flaps as well as a more detailed study of slot shapes, sizes, and positions.

Wind tunnels and apparatus.—Plans are under way for a rearrangement and expansion of the apparatus and facilities of the atmospheric wind-tunnel section. A larger wind tunnel is to replace the present 5-foot tunnel and a vertical tunnel designed primarily for the study of spinning will be added. The low-temperature tunnel, mentioned above, and another small tunnel previously used for miscellaneous experiments, have recently been added to the equipment of the section. The new arrangement will enable the space in the present wind tunnel building to be economically utilized, since, in addition to the housing of the four tunnels, about 2,000 square feet of office space will be made available.

In preparation for the design of the new tunnels, tests have been made in the small model tunnel on entrance and exit cones of a variety of shapes. Among other things, it has been found that the air vibration of an open-jet tunnel can be suppressed, that a honey-comb is unnecessary and even detrimental in a closed-return tunnel, and that a velocity increase of 4 to 1 in the entrance cone gives an excellent dynamic pressure distribution in the jet.

During the past year five new pieces of apparatus have been developed and put in operation. These are as follows: An attachment to the tunnel balances to enable measurement of roll and yaw due to ailerons; means of measuring directly the forces and pitching moments on an airfoil between end planes, together with provision for supplying air from a blower for slotted wing experiments; a multiple manometer for pressure distribution tests, with adjustable tubes to enable them to be spaced to suit the spacing of the orifices in the wing, making possible the fairing and integration of the pressure diagrams directly on the photostat record; a small dynamometer for measuring the rolling torques on wings in rotation; and the low-temperature wind tunnel previously referred to.

Variable Density Wind Tunnel.—At the beginning of the past fiscal year, after the airship model testing program had been completed, a fire, probably having its origin in an electric spark from a broken light bulb, completely destroyed the interior of the tunnel. The heat and the additional pressure caused by it damaged approximately 2,000 rivets and most of the seams in the upper part of the tank. Consequently, most of the year was devoted to redesigning and rebuilding the tunnel and balance.

The rivets and seams were recalked. The tank was equipped with a safety valve and a larger blow-off valve and then tested to its normal working pressure.

In contrast to the situation when the tunnel was first built, there was a wealth of information available, collected through experience with the original tunnel, upon which to base the design of the new interior. Although the tunnel had proved capable of producing data which correctly represented full-scale results, it had been criticized at times on the ground that the air flow in the test section was excessively turbulent. In the new design this turbulence was reduced by using a Prandtl type entrance cone. In addition to making the structure simpler

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and practically fireproof, several other improvements were incorporated in the new design. The most obvious difference is the change to an open-throat type of tunnel, experience with the previous tunnel and with the propeller research tunnel having shown the desirability of this change.

Although the new balance is not yet complete, the tunnel is again in operation. Preliminary tests showed that the energy ratio had been increased and the velocity distribution improved. Furthermore, drag tests on the Sperry messenger fuselage, using an auxiliary airship drag balance which was not in the tunnel at the time of the fire, gave results which were in good agreement with those from the original tunnel and from tests on the full-scale fuselage in the propeller research tunnel. It is expected that tests in the rebuilt tunnel will be conducted more rapidly and the full-scale results obtained with greater assurance than previously.

The new balance is, in general, similar to the old one, improvements being made in the details to increase the sensitivity of the drag and moment measurements and to make the balance mechanically more rigid. Other changes have been made in the balance to facilitate the reading and computing of the results of force tests.

Preliminary pressure distribution tests.—In the period between the completion of the tunnel and the installation of the balance, a series of pressure distribution tests is being conducted. These tests are of particular importance because they represent the first attempt to study directly scale effect on the pressure distribution over an airfoil. Previously the results of model tests have been compared with the results of flight tests, but the proportion of the discrepancy between them which should be attributed directly to scale effect on the airfoil has never been established. These tests will provide data at both a low and a high scale on the same airfoil mounted in the same way. Among the models which are being tested in this way is a symmetrical airfoil equipped with 10 per cent and 20 per cent chord flaps. The flaps will be set at angles ranging from 50° down to 50° up, so that scale effect on tail surfaces and ailerons as well as scale effect on their hinge moments may be studied.

Open-throat wind-tunnel research.—An investigation of the air flow in open-throat wind tunnels was carried out in the 6-inch wind tunnel to determine the best means of eliminating certain air vibrations which have been observed in some open-throat tunnels. The investigation was sufficiently extensive that the results should be very useful in designing tunnels of this type. A report covering this work has been prepared.

Scale effect.—Other methods of making high-scale model tests have been studied with a view to comparing the results of such methods when tests were made at the same Reynolds Number. Large objects at normal pressure and velocity may be tested in flight or in the propeller research tunnel. Small models may be tested at high density and usual velocity in the variable-density tunnel, or larger models may be tested at a lower velocity. Small models may also be tested at a moderate velocity in some fluid, other than air, having a lower kinematic viscosity; e. g., hot water. Another method, that of obtaining a high Reynolds Number by testing small models at normal pressure in air at very high velocities, has been given considerable thought, and as a result a high-speed wind tunnel has been built.

High-speed tunnel.—This piece of apparatus was designed to utilize the large amount of energy in the high-pressure air which had previously been discarded on the completion of each 20-atmosphere test in the variable-density tunnel. An air jet of extremely high velocity is produced by discharging the air from the variable-density tunnel tank through an annular nozzle in the high-speed tunnel. This jet induces a flow of air at a lower velocity through the throat of the tunnel, and in this induced air flow the models will be placed. Preliminary tests have not yet been completed, but results thus far indicate that it will be possible to obtain an air stream 1 foot in diameter having a velocity in the neighborhood of the velocity of sound.

Prediction of airfoil characteristics.—Data from airfoil tests in the variable-density tunnel have been carefully analyzed with a view to developing methods of predicting the characteristics of new airfoil sections. The results of tests on different airfoils at a high Reynolds Number are sufficiently consistent to make possible the development of combined empirical and theoretical equations which may be used to predict airfoil characteristics with an accuracy sufficient for most engineering work. A report on this subject has been prepared.

Three British airplane models.—The report covering the tests on the models of three British airplanes made in cooperation with the British Aeronautical Research Committee has been published. The results obtained from the tests on these models are compared with flight tests made on the airplanes at Farnborough. The fact that good agreement was obtained will do much to increase confidence in other results from the variable-density tunnel.

PROPELLER RESEARCH TUNNEL—*Tests of wooden propellers on VE–7 airplane.*—In order to develop the propeller-testing equipment of the new 20-foot propeller-research tunnel to the point where its operation and accuracy were satisfactory, and at the same time afford a comparison with flight tests and wind-tunnel tests on model propellers, several wooden propellers were tested on a VE–7 airplane. These identical propellers had previously been tested in flight, and similar models had been tested in a wind tunnel. The results of the flight and model tests were in fair agreement with those of the full-scale tests in the propeller research tunnel.

Effect of wings and tail surfaces on propeller characteristics.—Propeller tests were made on the VE–7 airplane with the tail surfaces removed, and with both the wings and tail surfaces removed. It was found that the effect of the tail surfaces on the propeller characteristics was negligible, but that the wings reduced the maximum propulsive efficiency and increased the power coefficient somewhat.

Tests on a series of metal propellers.—An adjustable-blade metal propeller was tested on the *VE–7* airplane at five different angle settings, forming a series varying in pitch. The efficiencies were found to be from 4 to 7 per cent higher than those of standard wooden propellers operating under the same conditions. The results of these tests are given in a new form convenient for use in selecting propellers of similar shape for aircraft.

Effect of tip speed.—An investigation was made of the effect of tip speed on the aerodynamic characteristics of a thin-bladed metal propeller. The propeller was mounted on the *VE–7* airplane and tested at tip speeds from 600 to 1,000 feet per second. It was found that the effect of tip speed on the propulsive efficiency was negligible throughout the range of the tests.

Drag of a wing radiator.—Tests were made on the left lower wing of the Williams racer in order to determine the effect of the wing radiator on the air-foil characteristics. It was found that the radiator, which had rather deep grooves, doubled the minimum drag of the portion of the wing which it covered, and also reduced the lift somewhat.

Racing-type air foils.—Tests were made on four racing-type air foils of 3-foot chord and 12-foot span in order to determine the high-speed characteristics. The air-foil sections tested were the N–9, N–38, C–62, and the N–46, which is a modified C–62 with rounded leading edge. The results indicate that the N–46 has about 12 per cent lower minimum drag then the regular C–62 section, and that both the N–38 and the N–46 have the exceptionally low minimum drag coefficient, $C_{D_{min.}}=0.0073$.

Drag of radial air-cooled engines.—The drag due to a Wright Whirlwind J–5 engine mounted on the nose of a cabin-type fuselage was measured with three different types of exhaust stacks: Short individual stacks, a circular cross-section collector ring, and stream-line cross-section collector ring. The drag due to the engine was found to be 85 pounds at 100 miles per hour with the individual stacks and 83 pounds at 100 miles per hour with each of the collector rings.

Effect of fillets on drag.—Tests were made to determine the effect of fillets between the wing and fuselage on the drag and propulsive efficiency of a high-wing cabin monoplane. It was found that at 100 miles per hour the drag was reduced 2 pounds by the use of fillets of 6-inch radius and 5.1 pounds by the use of fillets of 12-inch radius. The propulsive efficiency was very slightly increased by the use of 12-inch fillets.

Reports have been prepared on all of the above investigations.

Cowling and cooling of air-cooled engines.—The most extensive research yet undertaken in the propeller research tunnel—that on the cowling and cooling of air-cooled engines— is now under way and the testing is nearing completion. A Wright Whirlwind J–5 engine is being used in connection with both a cabin monoplane and an open-cockpit biplane. With the cabin fuselage the amount of cowling is varied in several steps from no cowling over the cylinders or crank case to complete cowling entirely inclosing the engine. Two forms are being tried, with and without a spinner. With the open-cockpit fuselage only the smaller cowlings are used, since the fuselage is too small to make it practicable to inclose the engine entirely. The engine is fitted with thermocouples to measure the temperatures of the cylinders and each cowling is modified if necessary until the engine cools satisfactorily. Then the drag and propulsive efficiency are found for each satisfactory cowling. The tests indicate a decrease in drag with increase in cowling and a large decrease with that which completely incloses the engine. The effect of individual fairings behind each cylinder will also be investigated.

Using the set-ups for the cowling tests, which provide different shapes of bodies, propeller tests with series of propellers of varying pitch are being made in order to provide data on propeller characteristics and body interference. Surveys of the air flow in the propeller plane are also being made in connection with the drag test on each body in order to provide information on body interference.

FLIGHT RESEARCH—*Airships.*—The airship research work during the past year has been and concentrated chiefly upon the analysis of the data obtained in the flight researches of last year and upon preparing this material for publication. The preliminary reports which were submitted to the Navy Department covering the pressure distribution and aerodynamic loads experienced by the U. S. S. *Los Angeles* in flight have been revised and rewritten and combined into one paper, which is to be Part I of a published report. Part II of this report is to be prepared by the Navy Department and will cover the stresses which were imposed in various structural members of airship simultaneously with the loads of Part I.

The results of the speed and deceleration tests conducted last year on the U.S.S. *Los Angeles*, with and without water-recovery apparatus installed, have been completed and submitted in report form to the Navy Department. The water-recovery apparatus, which consists of banks of tubes suspended between the hull and power cars, was found to increase the drag of the airship approximately 20 per cent.

A preliminary study of the velocity of air in gusty or bumpy weather, in which a series of measurements of the velocity of the air were recorded over a period of time when the air was particularly gusty or bumpy, has been brought to a conclusion. These preliminary measurements showed accelerations of air ranging from one of 121 feet per second which lasted ¼ second to one of 2 feet per second lasting 15¼ seconds. This investigation gave no information on the size or extent of a gust, and the next step planned in this research is to conduct a similar investigation covering a large area with a number of recording instruments operated synchronously

Airplanes.—A research is now in progress to determine the comparative maneuverability both at altitude and at sea level of a number of modern military airplanes of the pursuit and observation types. Particular attention is being directed toward the determination of the effect of water-cooled and air-cooled engine installations on maneuverability characteristics. Basically the comparison is being made upon the flight path attainable with each airplane in all conditions of flight, and for this purpose two methods of determining the airplane flight path in maneuvers have been developed. The first method makes use of data recorded in the airplane by the N. A. C. A. standard recording type instruments. The extreme accuracy of measurement required in this work has called for many refinements in the research instruments and in some cases has necessitated a redesign. The second method of flight path determination, which is used primarily as a check on the former, is made from the ground by means of a camera obscura simultaneously with the records obtained in the airplane. The camera obscura apparatus has been developed and constructed especially for this work and is so equipped that a series of photographs of a complete maneuver taken at ¼-second intervals are recorded on a sheet of film. Apparatus for use with the camera obscura for determining wind direction and velocity, and radio for control and synchronization of airplane and camera records have also been developed and used in this investigation. In addition to the specific data required for flight path determination, other measurements on each airplane are being obtained which will contribute to the general knowledge of airplane maneuverability and will assist in establishing an index of maneuverability that may be specified for new design. To date flight tests have been completed on one pursuit airplane and are now in progress on a second which is identical with the first with the exception of the engine installation.

As in previous years, a large portion of the flight research work has been conducted on the problems of determining the air loads experienced on airplanes in all conditions of flight, for the purpose of providing the necessary information for revising the loading specifications and methods of load computations now in use. A pressure distribution investigation has been completed on the entire supporting surfaces and control surfaces of a modern pursuit airplane. The results of this work are now being worked up and analyzed, and apparatus is being installed for an investigation of the pressure distribution on the fuselage of the same airplane. The results of a somewhat similar investigation on the air loads experienced on the tail surfaces of another type of pursuit airplane have been completed and a report has been prepared for publication. The results of this latter investigation confirm the advisability of revising present loading specifications, particularly those of pursuit airplanes, and the necessity of obtaining additional knowledge of the actual loads occurring in flight to provide a basis for such a revision, since it was found that the present specified load distribution was not exact, and that the specified total loads were too low to provide any safety factor in high-speed maneuvers. A program of pressure distribution research on airplanes has been prepared which includes complete investigations on cargo and observation type airplanes, and also includes the determination of the air loads on wing tips of various plan forms in steady and accelerated flight.

The research on the water-pressure distribution on the bottoms of various types of seaplanes at landing, take-off, and taxying has been continued throughout the year. The results of the tests conducted last year on a single-float seaplane have been completed and reported on. A similar investigation has been conducted on a twin-float seaplane, the results of which are now being prepared for publication. In the latter investigation, in addition to the positive water pressures which were measured over the whole float bottom, measurements of the negative water pressures were made at several points abaft the step. The maximum negative pressures measured were approximately 1 pound per square inch, while the maximum positive pressures were about 10 pounds per square inch. In general, the loads measured were considerably less than those now specified for design purposes, indicating the possibility of decreasing the weight of seaplane floats.

The take-off characteristics of airplanes have been studied to determine whether it was possible to establish a formula for the ground run of airplanes during take-off. As a part of this work tests have been conducted on an airplane with three different loads and three different propellers. The ground run has been measured with each load and each propeller, in winds of different velocities. The results of these tests, together with those of tests previously conducted on a number of service airplanes, have been undergoing analysis, but as yet no satisfactory expression for ground run has been derived and the study is being continued.

The increasing use of airplane wheel brakes has made it desirable to determine the effectiveness of brakes in decreasing the landing run and improving the taxiing qualities of airplanes. For this purpose tests are being conducted on an airplane, both with and without brakes, with different loading and wind conditions. In the same tests a study is being made of the most suitable method for the pilot to apply the brakes.

With the adoption of the oleo type landing gear or its equivalent in place of rubber type it appears possible to decrease the structural weight of the landing chassis and the fuselage members which take the landing load, because of the smaller loads imposed with the oleo type gear. In this connection a research is now in progress to determine quantitative values, for use in the design of landing gear, of the energy absorbed in both oleo and rubber type landing gears. The nvestigation includes dropping tests with several designs of each type gear, and will be accompanied by flight tests with each in which the accelerations occurring in a number of different kinds of landings will also be measured.

The general study of the problem of the recovery of an airplane from a spin has been continued this year and has consisted mainly of a compilation of the data pertinent to the problem. Special attention has been directed toward the effect of mass distribution on spins and the policy has been established of measuring the moments of inertia of all airplanes undergoing test at the laboratory and such others as evidence any unusual spinning characteristics. As a result, the moments and ellipsoids of inertia of several airplanes of normal spinning characteristics and of one in which recovery from spin is very difficult have been measured. In addition, incidental to the researches on pressure distribution and maneuverability mentioned above, considerable information has been obtained on the wing and tail surface loads and on the flight path, attitude, rate of rotation, axis of spin, etc., occurring in spins. A comparison of the ellipsoids of inertia of airplanes having normal and abnormal spinning characteristics, which is expected to indicate desirable dispositions of weight for new designs, is now in progress.

Preparations are being completed for a flight research to determine the effectiveness of various types of ailerons in producing lateral control. An airplane is to be rebuilt to use interchangeable ailerons and at the same time is to be equipped with flaps and spoiler gear. A stress analysis of the wing structure is at present in progress.

The formation of steam or the collection of rain, snow, or ice on windshields, particularly those of cabin type airplanes, very often seriously hampers the pilot's view and introduces an additional hazard of piloting. A research is now in progress to determine the possibility of eliminating this hazard under all atmospheric conditions. One possible solution is the use of a windshield containing an opening which is large enough for a reasonable amount of visibility but through which the entrance of rain, snow, etc., or an objectionable amount of air, is prevented by the air flow over the opening. Preliminary tests are now being conducted on a model cabin airplane in which an attempt is being made to accomplish the above by regulating the air flow either by means of the shape of the windshield or by cowling in front of the windshield.

WASHINGTON NAVY YARD

Airplane models.—During the past year the 8-foot wind tunnel at the Washington Navy Yard has been employed, as in the past, almost entirely in testing airplane models and airfoils. Twenty-nine complete tests in pitch and yaw were made on 17 models representing 15 designs. In addition to these tests, approximately 20 partial tests were made to investigate particular features such as control effectiveness, interference, etc. In so far as practicable the routine work is planned to include items of a research nature that arise in the course of design studies. This policy permits the carrying of research work along with the design testing without holding up the latter.

A number of the wind-tunnel tests made during the past year were on types for which flight-test data are now available. It is of interest to note that the predictions based on the model test data have been uniformly satisfactory. For example, the average agreement in maximum speed is well within 1 per cent, with an extreme deviation of less than 2 per cent. In the matters of stability and control the reliability of the wind tunnel has been demonstrated conclusively in the past, but data obtained during the past year in several cases of slight instability and slight deficiency of control are very convincing.

Airfoils and wings.—Routine tests have been made on 25 airfoil models, including the Navy series N–25 to N–46, the Göttingen sections 443, 444, and 445, and the N. A. C. A. M–6 and M–12. Several sections in the Navy series have sufficient merit to justify tests in the variable-density wind tunnel.

Control surfaces.—Measurements have been made for the control effectiveness of 5 rudders, 2 elevators, and 2 ailerons. These tests were made on various airplane models in connection with the problems of control-surface design. One aileron was tested for hinge moments, using a special model constructed for this purpose.

Floats and fuselages.—Tests of varying degrees of completeness have been made on eight seaplane floats. In all cases each model was tested for scale effect at 0° pitch and yaw and for lift and drag in pitch. Four additional models are now awaiting test.

Tests in pitch and yaw have been completed on four body models in continuation of a previous series and nine additional models are now awaiting test. This work is being carried out in the 4-foot wind tunnel.

Radiators.—A rather extensive research has been made on the cooling properties of wing radiators of various types, using sections of full-scale radiators where available.

Handley-Page slotted wing.—Two models of the Handley-Page slotted wing have been tested, one for the operation of the automatic slot and the other for air forces on the leading airfoil. The satisfactory direct measurement of air forces on the leading airfoil required unusual care, but the wind-tunnel staff is convinced that the method used is as reliable as the pressure-distribution method.

Lighter-than-air craft.—No tests on lighter-than-air craft have been made since the completion of the extensive research on the rigid airship designs last year. However, considerable work has been done in the design and construction of a new type of oscillator for measuring damping moments. This oscillator when completed will be used to measure damping moments on several models now awaiting such tests.

Miscellaneous tests.—An extensive research has been made in the 4-foot wind tunnel in studying the resistance of wire screens of varying wire and mesh sizes. The investigation is being completed by interference measurements on parallel rods and struts with variable spacing.

Tests have also been made in the 4-foot wind tunnel on a series of cylinders, disks, and other shapes. Additional tests of this nature are now contemplated.

A study is now being made to devise simple methods of measuring lateral stability derivatives with the view of adopting these tests as a part of the routine work on new designs.

BUREAU OF STANDARDS

Wind-tunnel investigations.—A final report has been prepared and submitted to the committee for publication as a technical report on the measurements of the characteristics of 24 airfoil sections at speeds of 0.5, 0.65, 0.8, 0.95, and 1.08 times the speed of sound. The airfoils were of 1-inch chord and extended entirely across the 2-inch air stream. The aspect ratio on these tests was rather small, and in order to determine the influence of aspect ratio at high speeds new equipment has been assembled to permit the use of aspect ratios of 6 or more. The equipment consists of three large tanks, each having a capacity of about 1,000 cubic feet, which may be filled with air under a pressure of 20 or 30 pounds per square inch. By means of a quick-opening valve the air in the three tanks may be released through a 6 or 8 inch nozzle, the speed dropping from the speed of sound to about one-half the speed of sound in about 20 seconds. An automatic balance is now being designed to give continuous records of the lift and drag on airfoils during the discharge period.

Apparatus has been assembled and used for the measurement of the time variations of air speed in wind tunnels. The speed variations produce changes in temperature and hence in the resistance of a fine platinum wire about 1 centimeter long and 0.0017 centimeter in diameter, which is heated electrically by a constant heating current. The variations in the voltage drop across the wire are amplified by means of a resistance-coupled direct-current amplifier. A theory has been worked out for the response of a hot wire as a function of the frequency and the theory has been checked experimentally and found to be substantially correct. It has been found possible to incorporate in the electrical circuits a device which compensates automatically for the effect of the lag for frequencies up to 150 cycles per second. A traverse across the working section of the wind tunnel shows that the stream consists of a core of approximately uniform speed in which the mean amplitude of the speed variation (turbulence) is small and uniform throughout the cross-section. This core is surrounded by a ring about 3 inches in thickness near the wall in which the speed decreases according to a power of the distance from the wall and the turbulence increases. Near the wall the percentage variation of local speed reaches a value of about ± 15 per cent.

The investigation of wind pressure on chimneys has been continued. The experimental chimney, 10 feet in diameter and 30 feet high, on the roof of one of the buildings of the Bureau of Standards has been mounted on sylphons for the measurement of overturning moments. An installation for pressure-distribution measurements has also been made on the new power-plant stack at the Bureau of Standards. The observations obtained so far are not sufficiently numerous to justify a statement of conclusions at this time.

In cooperation with the aeronautics branch of the Department of Commerce and the National Advisory Committee for Aeronautics, measurements are being made of the rolling and yawing moments produced by ailerons of various chords and spans on 10 inch by 60 inch models of Clark Y and U. S. A. 27 wing sections. The results for an angle of attack of 4° have been submitted to the committee for publication as a Technical Report.

Aeronautic instrument investigations.—The work on aeronautic instruments has been conducted in cooperation with the Bureau of Aeronautics of the Navy Department and the National Advisory Committee for Aeronautics.

The purchase specifications for service aircraft instruments for the Bureau of Aeronautics require that a fraction of the number purchased be given type tests, which relate to the effect of temperature, vibration, elastic defects, and other factors. This testing increased greatly during the past fiscal year. In addition to the primary purpose of determining whether the instruments meet the specifications, the test data have been a valuable source of information in the preparation of new specifications.

The development program covered new and improved apparatus for testing aircraft instruments, improvements in service instruments, and the development of aircraft instruments for special purposes. Two vibration racks of new design were constructed which permit the independent control of frequency and amplitude of vibration. One of these racks is now being used to accumulate data on the effect of these factors on various types of service instruments as a basis for new specifications. An apparatus has been constructed which oscillates with simple harmonic motion comparable to the minor oscillations of an airplane. It is large enough to carry two observers and is for the purpose of studying the effect of small accelerations on the artificial horizons of sextants. An electric resistance thermometer was constructed for the Bureau of Aeronautics for use in flight testing. An earth inductor compass with the Heyl-Briggs method of indication was constructed for experimental purposes. Definite progress has been made in the development of a distant indicating tachometer of the direct-current magneto type for use in multi-engined airplanes. The completed instrument will probably consist of a small commercial magneto and a voltmeter with a pointer motion of 270°, both compensated for temperature. Development work on other types of distant indicating tachometers is also in progress.

Research has continued on the properties of elastic materials used in instrument design. A theoretical investigation of tuning forks of particular shape has been made, preliminary to the use of tuning forks of this design for the purpose of determining the elastic hysteresis modulus of various metals. The change in the modulus in torsion of diaphragm and spring metals in the temperature range + 50° C. to −20° C. for various fiber stresses has been studied. A report has been submitted to the committee for publication on pressure elements of constant logarithmic stiffness for a temperature-compensated altimeter. A report has been prepared on the relations between time, fiber stress, and elastic afterworking, or drift, based largely on the experimental results given in the committee's Technical Note on tension experiments in diaphragm metals.

The results of the investigation of damping liquids for aircraft instruments have been submitted to the National Advisory Committee for Aeronautics for publication. The report includes data on the viscosity, change in viscosity, and lowest useful temperature of a number of selected liquids and mixtures in a temperature range from +30° to −20° C. The liquids include those commonly used in aircraft compasses, inclinometers, bubble horizons, and other instruments.

MATÉRIEL DIVISION, ARMY AIR CORPS

General.—The high-speed 14-inch wind tunnel has been dismantled throughout the past year, and the 5-foot wind tunnel has not been in operation since the middle of January, 1928, on account of the moving of the tunnels to the new Wright Field. Consequently the amount of wind-tunnel work carried on has been limited.

Development of apparatus.—An automatic air-speed control for the 5-foot wind tunnel has been developed and built, but not tested. This control depends for its operation upon the cutting off of the light, by means of a colored manometer liquid, in front of a photo electric cell, which actuates a series of relays to vary the motor field resistance.

Airplane model tests.—Only one routine model test was made in the 5-foot wind tunnel. This test was made on a 1/24-scale model of the Douglas O-2H observation airplane at 40 miles per hour on the N. P. L. balance.

Wind-tunnel investigations.—An intensive study was made to determine the characteristics of the horizontal tail surfaces of an airplane, particularly the relation between the elevator hinge moment and the total tail moment. The study was made in connection with the theoretical analysis of longitudinal stability made by the matériel division. Wind-tunnel tests were made upon a 1/5-scale model of the Curtiss AT-4 fuselage and tail surfaces.

As a result of the directional instability observed on several of the new type airplanes, model tests were made in the wind tunnel to determine the remedy that would be the most effective in overcoming this difficulty. These tests consisted in the measuring of the effect upon the yawing moments caused by varying the size and type of vertical tail surfaces, by increasing the length of fuselage, and by the replacing of a single fin and rudder with double fins and rudders.

Tests were made to determine the merits of two methods suggested for obtaining lateral control of airplanes. The principle of the first method was based on the reduction of lift, by means of a device placed on the leading edge to destroy the air flow. The second method consisted in hinging the wing tips, thus causing the lift to vary because of the increase or decrease of effective area with the angle of the wing tips.

The path of a 25-pound demolition bomb for the first 5 feet after release from an airplane was determined by dropping dummy bombs in the wind tunnel at air speeds up to 250 miles per hour.

Miscellaneous tests.—The miscellaneous testing consisted of various calibration and comparative tests on wind-driven generators, earth-inductor compasses, Venturi tubes, and air-speed indicators.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

ORGANIZATION

The committee on power plants for aircraft is at present composed of the following members:

Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.
George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.
Henry M. Crane, Society of Automotive Engineers.
Prof. Harvey N. Davis, Stevens Institute of Technology.
Dr. H. C. Dickinson, Bureau of Standards.
William F. Joachim, National Advisory Committee for Aeronautics.
Lieut. Commander James M. Shoemaker, United States Navy.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.
Capt. T. E. Tillinghast, United States Army, matériel division, Air Corps, Wright Field.

FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power-plant research in progress or proposed.
4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power-plant research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Corps or the Bureau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ENGINE RESEARCH—*Aircraft oil engines.*—The outstanding improvement in the performance of the committee's single-cylinder oil engines during the past year has been the attainment of high power output and increased flexibility of the engines with low maximum cylinder pressures.

Engine performance—High air turbulence.—The investigation undertaken to determine the effect of high turbulence of the combustion air, as influenced by the design of cylinder head, on the performance characteristics of a high-speed oil engine have been continued with the No. 3 cylinder head having a pear-shaped precombustion chamber. The factors under investigation include the determination of the effects on engine performance of extending the fuel-valve nozzle into the bulb for distances of 1½, 1, and ½ inch and directing the fuel charge toward the center of the $\frac{9}{16}$-inch diameter bulb-to-cylinder orifice. A series of orifices will be tested for each nozzle extension to determine the orifice diameter and length of nozzle extension which will give maximum engine performance.

Tests are in progress to determine the engine performance obtainable for a complete range of fuel quantities from zero load to full load with the 1½-inch extension of fuel-valve nozzle. The orifices to be tested range from 0.020 inch to 0.035 inch in diameter. For these tests the start of injection, duration of injection, and spray start and cut-off characteristics of the fuel-injection system are being determined at an engine speed of 1,500 r. p. m. by observing the fuel sprays with an oscilloscope when injected into the atmosphere.

Engine performance—Moderate air turbulence—Performance at low cylinder pressures.—Investigations have been continued with the cylinder head having a vertical disk-type combustion chamber formed between the horizontally arranged inlet and exhaust valves. A moderate degree of air turbulence is produced in the combustion chamber of this cylinder head by displacing the air between the piston and the cylinder head through a large rectangular orifice into the combustion chamber. The effects on engine performance of various combinations of injection-valve orifices of small diameter located in one plane in the fuel-valve nozzle and designed to distribute the fuel charge throughout the combustion chamber are under investigation. The results obtained indicate that it is possible to lower the maximum cylinder pressures considerably in a high-speed oil engine and still obtain good engine performance by controlling the rate of fuel injection and proportioning the size and number of the orifices in the fuel-injection valve.

Fuel-injection valve nozzles having 3, 5, and 7 round orifices have been tested. Maximum engine performance to date has been obtained with an injection valve located in the center of the cylinder head at the top of the combustion chamber using a nozzle having seven orifices of small diameter. The diameters of the five orifices delivering fuel to the air in the upper portion of the vertical disk-shaped combustion chamber have been maintained constant and the diameters of the two main orifices delivering fuel to that portion of the air charge in the rectangular orifice directly above the piston crown have been varied from 0.010 to 0.021 inch. The engine performance has been determined for each fuel-injection-valve nozzle.

The maximum distance from the fuel-valve nozzle to the top of the piston is 4½ inches, with the piston at top center. The carbon formation on the piston showed that for main orifices of 0.012-inch diameter and larger the fuel sprays impinged on the piston.

The maximum engine performance with this cylinder head assembled on an N. A. C. A. single-cylinder test engine having a 5-inch bore and a 7-inch stroke, a compression ratio of 14 full-load fuel quantity (i. e., that fuel quantity giving 15 per cent excess air in the cylinder), and 1,500 r. p. m., was obtained with the nozzle having two main orifices of 0.018-inch diameter. The results showed that with 15 per cent excess air in the cylinder the indicated mean effective pressure increased from 99 to 122 pounds per square inch, with increase in orifice diameter from 0.010 inch to 0.018 inch. The corresponding fuel consumption decreased from 0.60 to 0.49 pound per indicated horsepower per hour. The maximum cylinder pressure, as indicated by a very light-weight disk-type maximum-cylinder, pressure indicator, did not exceed 500 pounds per square inch. An increase in main orifice diameter from 0.018 inch to 0.021 inch resulted in a slight decrease in indicated power.

At a fuel quantity giving approximately three-fourths full load torque, which corresponds to engine operation at cruising speeds, and maximum cylinder pressures below 500 pounds per square inch, the indicated mean effective pressure varied from 84.5 pounds per square inch with an orifice diameter of 0.010 inch to 90 pounds per square inch with an orifice diameter of 0.018 inch. The indicated fuel consumption for the nozzle with the two main orifices of 0.018-inch diameter was 0.39 pound per indicated horsepower per hour. The maximum brake mean effective pressure for cruising conditions, assuming a mechanical efficiency of 85 per cent, would be 76.5 pounds per square inch, and the corresponding fuel consumption 0.46 pounds per brake horsepower per hour.

Engine performance—Moderate air turbulence—Performance at medium cylinder pressures.—At 1,500 r. p. m., full-load fuel quantity, and a maximum recorded cylinder pressure of 665 pounds per square inch, the engine developed a maximum indicated mean effective pressure of 130 pounds per square inch with a corresponding fuel consumption of 0.45 pound per indicated horsepower per hour. Based on a mechanical efficiency of 85 per cent for multi-cylinder operation this performance gives a brake mean effective pressure of 113 pounds per square inch and a fuel consumption of 0.53 pound per brake horsepower per hour. The maximum brake mean effective pressure developed by the Liberty 12 engine is 123 pounds per square inch and the fuel consumption 0.53 pound per brake horsepower per hour. The performance obtained for the engine operating at cruising power with a maximum cylinder pressure of 650 pounds per square inch would be 76 pounds per square inch brake mean effective pressure and 0.44 pound per brake horsepower per hour fuel consumption. The single-cylinder engine can be idled at 150 r. p. m. and rapidly accelerated without knocking or missing to a rotative speed of 2,100 r. p. m.

Cylinder-head design.—The investigation to determine the effect on engine performance of various degrees of turbulence brought about by cylinder-head design will be continued with the cylinder head having a horizontal disk-type combustion chamber and a short large-diameter displacer on the piston. This cylinder head has been machined and the assembled cylinder head and valve gear are ready for installation and testing.

Two-stroke cycle gasoline-injection engine investigation.—The pursuit-type airplane having high speed, rapid climb, and the highest degree of maneuverability requires a power plant having a large power output with minimum weight. Because of the theoretical increase in power and decrease in engine weight when operating on the 2-stroke cycle, a radial air-cooled engine having gasoline injection and electric ignition is a type of power plant inherently suitable for this class of service. The fundamental factors affecting the operation of this type of engine will be investigated with a single-cylinder 2-stroke cycle air-cooled engine having a 4⅝-inch bore and a 7-inch stroke. The engine will be designed to operate with a high compression ratio and a maximum rotative speed of 2,000 r. p. m.

Cylinder assembly.—The cylinder design for the 2-stroke cycle test engine will consist of a standard Liberty air-cooled engine cylinder altered for 2-stroke cycle operation and for assembling on the crank case of an N. A. C. A. universal engine. Ports will be machined in the lower portion of the cylinder barrel for admission of the scavenging and combustion air. The exhaust gases will be discharged through two standard poppet valves in the cylinder head. The design of the exhaust-valve operating mechanism and the combustion-chamber shape have been completed. The valve-operating mechanism consists of a cam mounted on the engine crank shaft, a spring-loaded cam follower and tappet, and individual push rods for each exhaust valve. This type of valve-operating mechanism is readily adaptable to radial engines having push rods operated from a cam disk. The combustion chamber will be formed by the domed head of the standard Liberty air-cooled engine cylinder and a special aluminum-alloy piston having a concave head and moderately beveled edges. A detailed analysis has been made of the design of the combustion-chamber shape in order to meet definitely the fundamental requirements of the reliability of ignition, high-brake mean effective pressure, economy, and flexibility.

Combustion air system.—The combustion air for this engine will be supplied by an N. A. C. A. Roots type supercharger driven by an electric motor. The mounting of the supercharger outlet in relation to the air manifold closely simulates the type of mounting which would be required for a 2-stroke cycle multicylinder engine. Since the supercharger which will be used in this research has sufficient air capacity for operating a multicylinder, 2-stroke cycle engine, the excess air supplied by the supercharger will be by-passed under pressure conditions in the engine manifold, simulating those in a multicylinder engine manifold of a 2-cycle radial engine. In order to maintain practically constant air pressure in the inlet-air manifold of the experimental engine, an air by-pass valve consisting of a large number of rectangular spring-loaded steel strips and a housing integral with the manifold is being designed. Because of the low inertia of the moving parts of this type of by-pass valve, the pressure in the inlet air manifold will remain practically constant regardless of any tendency to surging of the air in the line due to the opening and closing of the inlet ports in the cylinder. The quantity of scavenging and combustion air required for the operation of the engine over a full range of engine speeds and loads will be determined by means of Venturi meters calibrated by a gasometer. The inlet-air manifold will consist of a 2-piece aluminum casting bolted directly to the steel cylinder.

Fuel-injection system.—The design of a fuel-injection system for the 2-stroke cycle engine which will give reliability and good fuel economy is complicated by the fact that the low air pressures into which the gasoline is injected permit considerable penetration of the sprays. Tests made with the N. A. C. A. spray photography apparatus showed that orifices 0.004 inch in diameter, even when used with low injection pressures, gave excessive penetration for this size of cylinder. It has been necessary, therefore, to design a new type of fuel-injection nozzle which will give a high degree of fuel atomization, but only sufficient penetration to permit the efficient distribution of the fuel-spray particles in the combustion air. The design of the fuel-injection valves has been started.

The fuel-injection pump for this engine will consist of a cam-operated fuel-injection pump driven from the engine crank shaft. The start and stop of injection will be controlled by the closing and opening of a fuel by-pass valve. The design of this fuel-injection pump has also been started.

Cooling-air system.—The cooling-air system for the 2-stroke cycle engine, consisting of a conoidal-type blower driven by electric motor and suitable air ducts, has been designed, constructed, and partially tested. The temperatures of the cylinder head, cylinder barrel, and fins will be recorded for all test conditions by fine wire thermocouples and recording pyrometers.

Fuel-injection pumps and valves—Fuel valve extensions.—In order to determine the effect of the position of the fuel valve nozzle and the turbulance of the cylinder air on the performance of a cylinder head having a precombustion chamber, it has been necessary to develop a method for preventing the rapid oxidation of the fuel-valve nozzle extensions when extended into the precombustion chamber for a maximum distance of 1½ inches. The extension must operate at such a temperature that any fuel blown onto it by the air movement in the cylinder is immediately vaporized and does not carbonize on the nozzle extension. Several designs of copper fins have been investigated, but the rapid oxidation of the copper fins resulted in a loss in the heat-transmission capacity of the copper and the consequent failure of the fins. In the present design, the finned surfaces have been replaced by three concentric insulating stainless-steel sleeves. The sleeves are machined so as to provide an insulating air gap 0.004 inch thick between each sleeve and the nner sleeve and the valve-nozzle extension. Preliminary engine tests made at 1,500 r. p. m. showed that the outer insulating sleeve attained a temperature of about

550° F. for one-half its length and was exceptionally clean and free from carbon. The colors on the tip of the fuel-valve stem and nozzle indicated a temperature of about 480 to 500° F., but the remainder of the stem maintained the original bright, polished surface.

Fuel-injection pumps and valves—Dual-stem fuel-injection valve.—The single-injection rate fuel-injection valve used with the No. 7 cam-operated fuel-injection pump in the investigation made to determine the effect on engine performance of various combinations and sizes of small-diameter orifices did not permit the attainment of the varying fuel-injection rates for which the cam-operated fuel-injection pump was designed. A dual-stem fuel-injection valve has therefore been designed, having spring-loaded lapped stems with opening pressures of 2,000 and 4,000 pounds per square inch. The orifice diameters of the fuel-valve nozzle have been proportioned to give uniform distribution of fuel sprays throughout the vertical disk-type combustion chamber of cylinder head No. 4. The injection valve is being constructed.

Multi-cylinder fuel-injection systems.—The previous work of the committee has been limited to the investigation of injection problems occurring in fuel-injection systems for single-cylinder aircraft-type oil engines. These investigations have not included data on the hydraulic distribution and injection problems encountered in the operation of fuel-injection systems for aircraft-type multi-cylinder oil engines. An investigation will therefore be made to determine the degree of application of the results obtained with fuel-injection systems for single-cylinder engines to multi-cylinder engine operation.

A six-plunger cam-operated fuel-injection pump having the start and duration of fuel injection controlled by the closing and opening of fuel by-pass valves has been designed for this investigation. The fuel-pump controls, which have been designed to simulate the throttle and spark controls of a carburetor-type engine, permit a variation in the start of injection of 65 crank degrees and a variation of 70° in the time at which the fuel by-pass valve may be opened to stop injection. The angular position of the cams may be varied 20 crank degrees in relation to the engine crank shaft while the engine is running. A method of compensating for irregularities in machining and wear which will insure accurate timing of injection for each pump plunger by the maintenance of the proper clearances in the by-pass valve operating mechanism has been incorporated in the design of the pump. The castings for this pump have been received and the machining of the pump is in progress.

Aircraft-oil-engine pistons.—Engine tests have been completed to determine the operating characteristics of the Y-alloy skeleton-type high-speed oil-engine pistons having the thrust faces of the piston lubricated by oil under pressure from the piston pin. This design of piston weighs only nine-tenths as much as the standard Army Liberty-type aluminum-alloy piston and is 30 per cent stronger. The factors studied have included the determination of the permissible rate of oil delivery to the thrust faces of the piston, the possible reduction in clearance between the piston and cylinder with satisfactory engine operation, and the piston friction and sealing ability of various combinations of narrow-compression and oil-scraper piston rings.

The results of the tests showed that it is possible to increase the quantity of oil delivered to the thrust faces of the piston at 1,500 r. p. m. to the point where a new film of oil 0.005 inch thick is delivered every stroke of the piston over the entire cylinder surface. This large quantity of oil cools the piston skirt so that the thrust faces operate at very low temperatures. The combination of compression and oil scraper rings which prevent the passing of the lubricating oil to the combustion chamber consists of two compression piston rings 0.100 inch wide and three oil scraper rings 0.100 inch wide. The oil consumption with this type of piston ring assembly with pressure lubrication to the piston is less than that of the standard Liberty aircraft engine. Satisfactory engine operation is being obtained over the complete range of engine loads from zero load to approximately 25 per cent overload with the piston to cylinder clearance, measured at the piston thrust faces, reduced to 0.010 inch on a 5-inch cylinder diameter. The use of these aluminum-alloy pistons in both the committee's single-cylinder oil engines has lowered the piston temperatures, decreased the wear of the pistons and liners, and resulted in quieter engine operation at all speeds and loads.

Maximum cylinder-pressure indicators—Disk type.—Tests have been continued with the balanced-pressure disk-type maximum cylinder-pressure indicator to determine the sensitivity of the disk in indicating high fast-rising cylinder pressures. Two disks having area-weight ratios of 0.475 and 0.0957 were tested at an engine speed of 1,500 r. p. m. A range of cylinder pressures having different rates of pressure rise and values of maximum intensity was obtained by varying the injection advance of the engine from 4° to 12° before top center. The disk having the area-weight ratio of 0.475 gave consistently higher pressure readings. The difference in the pressures indicated by the two disks varied from 10 pounds per square inch at an injection advance angle of 4° before top center to 310 pounds per square inch at an injection advance angle of 12°.

Maximum cylinder-pressure indicators—Electrically operated type.—A balanced-pressure diaphragm-type maximum cylinder-pressure indicator has been designed, constructed, and assembled for testing in an engine. The diaphragm element of this indicator is 0.004 inch thick, 0.5 inch in diameter, and is clamped between two surfaces so that its free diameter is 0.375 inch. The maximum movement of the center of the diaphragm is 0.005 inch in one direction from its unstressed position. Preliminary tests indicate that the accuracy of this instrument is limited only by the pressure gauges for measuring the balancing air pressures. The contact between the diaphragm and its support at equality of cylinder gas and balancing pressure is at present indicated by means of "clicks" in a head phone. A visual means for indicating this contact is being developed so that simultaneous observations may be taken of the maximum cylinder pressures of all cylinders in a multi-cylinder engine.

Investigations completed—Performance of a 4-part automatic injection valve.—As previously reported, the design, development, and testing on an engine of a new type fuel-injection valve having only four parts and suitable for disk or conical-shaped combustion chambers have been completed. The results of this investigation are being prepared for publication in two reports entitled "The Injection Characteristics of a Four-Part Automatic Injection Valve" and "High-Speed Oil Engine Performance with a Four-Part Automatic Injection Valve." The first of these reports will contain a description of the valve, a theoretical analysis of the injection characteristics of this type of valve, and the results of the engine development and bench tests. The second report will present the engine performance obtained with this type of fuel-injection valve when used with the standard N. A. C. A. universal test engine having a pent-roof-shaped combustion chamber. The factors investigated include the effect of speed, fuel quantity injected per cycle, injection-advance angle, valve-opening pressure, compression pressure, and preheating of the fuel oil on the performance of the engine at a speed of 1,500 r. p. m.

Investigations completed—Heat losses from engine cylinders.—A theoretical investigation has been made to determine the effect of bore-stroke ratio and shape of cylinder-head on the heat losses from an engine cylinder due to radiation and conduction. Relative heat losses have been calculated for four cylinder-head shapes; i. e., domed, two semidomed, and flat, and a range of bore stroke ratios from 0.6 to 1.4. A report entitled "The Effect of Bore-Stroke Ratio and Cylinder-Head Shape on the Radiation and Conduction Losses from an Engine Cylinder" is being prepared for publication.

Investigations completed—Injection-system characteristics.—A method has been developed for the determination of the start, duration, and cut-off characteristics of fuel-inject on sprays when injected into the atmosphere from a fuel-injection system operated on an eng ne. Some test results obtained with an impact-type fuel-injection pump and a spring-loaded automatic fuel-injection valve have been published in a Technical Note entitled "The Determination of Several Spray Characteristics of a High-Speed Oil-Engine Injection System with an Oscilloscope."

Investigations completed—Cylinder-pressure indicators.—A part of the investigation to determine the methods and instruments for indicating the maximum gas pressures in high-speed internal-combustion engine cylinders has been completed and the results published in a report entitled "The Measurement of Maximum Cylinder Pressures." Five maximum cylinder-pressure devices have been designed, developed, and tested, in addition to the testing of three commercial indicators. The results of the investigation at present indicate that the greatest degree of accuracy can be obtained with a gas balanced-pressure diaphragm or disk-type indicator.

FUEL-INJECTION RESEARCH.—The N. A. C. A. spray photography equipment has been used for further photographic investigation of the characteristics of injection systems and of fuel sprays produced by them. Injection pressures up to 12,000 pounds per square inch and chamber pressures up to 600 pounds per square inch, the air being either still or turbulent, are used in the investigation. Twenty-five pictures of each spray are obtained at rates of from 2,000 to 4,000 pictures per second on photographic film. The pictures are taken with an exposure of less than one-millionth second and show the start, development, cut-off, and distribution of the sprays.

Injection time lags.—The design of the injection system of a high-speed oil engine necessitates knowledge of the time lags involved in the operation of the system. An investigation of the velocity of pressure waves and the time lags of the spray photography injection system was completed during the previous year. The experimental data have been analyzed and formulæ have been derived for computing the velocity of pressure waves in the injection tubes and the lags due to the time required for the wave to travel the injection tube and cause the injection valve to open and inject oil. The effects of length of injection tube, injection pressure, initial tube pressure, and valve-opening pressure on the pressure-wave velocity and the injection lags are expressed by the formulæ. These formulæ are applicable to the computation of the lags of any injection system using pressure-wave injection. A report covering this investigation is being prepared for publication.

Injection-valve operation.—The operation of the spray photography injection system has been studied both by mathematical analysis and by taking records of the motion of the injection timing valve. The timing valve stem was held to its seat by a helical spring under light load, so adjusted that the hydraulic pressure on the stem actuated it immediately after it had been lifted mechanically from its seat. The motion of the stem was recorded photographically and the pressure variations at the stem seat were analyzed. The effect of the length of injection tube was also studied in this connection. The results of the analysis of the pressure variations and the equations of motion of the timing valve stem are applicable to a spring-loaded automatic injection valve. A report on this investigation is being prepared for publication.

Effect of air turbulence on spray characteristics.—Among the factors that affect the mixing of the particles of oil spray with the combustion air in the engine cylinder, air turbulence is usually considered to be important. An investigation was therefore carried out with the spray-photography apparatus in order to determine the effects of an air flow of known direction and velocity on oil sprays in dense air. The spray-photography chamber was arranged to simulate the shape of an engine combustion chamber of the flat disk-shaped type. Air was blown through the chamber against the spray at a maximum velocity of 60 feet per second, a static pressure of 200 pounds per square inch being maintained in the chamber. The oil was injected from a seven-orifice nozzle and from three single orifices of different sizes. It was found that air turbulence had very little effect on spray penetration, but it increased the width and probably the atomization of the sprays. The air flow did not materially affect the sprays until about 0.004 second after the start of injection. A report on the results of this investigation is being prepared for publication.

The characteristics of oil sprays from several multiorifice nozzles, each having a different combination of orifice sizes, have been studied. Increasing the size of the large orifices in the nozzles decreased the penetration of the sprays from the small orifices in the nozzles as much as 15 per cent. The penetration of the sprays as measured by means of spray photographs checked the penetration in the engine as indicated by the carbon deposit on the piston.

Ignition lag of oil sprays.—The determination of the ignition lag of oil sprays is of considerable importance in the design of high-speed oil engines. Pending the completion of the design and construction of the spray-photography-combustion equipment, which will closely simulate engine conditions, tests have been made using an electrically heated sheet-metal chamber large enough to prevent the spray from coming in contact with the walls of the chamber. Because of the fact that atmospheric air pressure only was used in the chamber, the ignition lag was extremely long compared to that in an engine.

Spray-combustion-photography equipment.—The design of new apparatus to be used in connection with the present spray-photography equipment in order to make possible the study of the characteristics of combustion of atomized fuels for oil engines is well under way. Several preliminary designs have been completed, the final arrangement of the apparatus has been decided upon, and detail drawings have been started.

The apparatus as designed at present will consist of the spray-combustion chamber proper, the electric-heating chamber, the turbulence cylinder, and the motors, shafts, and clutches for operating the injection and turbulence apparatus. The spray chamber will have quartz-glass windows by means of which it will be possible to photograph the oil-spray combustion. Air will be circulated from the heater through the spray chamber by means of a 2-inch 2-bladed metal propeller operating at high speed. The turbulence apparatus will consist of a cylinder containing a piston operated by a connecting rod and crank so as to furnish air circulation with the desired velocity and in the desired direction during injection and combustion of the oil spray. The combustion chamber, heating chamber, and turbulence cylinder will be cast of nichrome in two parts and will be bolted together in one compact unit. The spray chamber, injection apparatus, and camera will be on top of a cast-iron table, the remainder of the apparatus being inclosed beneath the table top.

With this apparatus it will be possible to photograph oil sprays and their combustion when injected into air under conditions similar to those in an oil engine during injection. Temperatures up to 1,400° F. and pressures up to 600 pounds per square inch may be produced. The injection apparatus may be operated alone or in conjunction with the turbulence apparatus to give the desired turbulence. A complete temperature survey of the combustion chamber will be possible by means of special thermocouples, and the pressure rise during combustion will be recorded by means of a pressure indicator.

Various high-speed photographic films have been investigated in order to determine the best type of film for recording the combustion of oil sprays. High-speed panchromatic films from three manufacturers were found to record the combustion, and the best film was selected for future use.

SUPERCHARGER AND COOLING RESEARCH—*Supercharger analysis.*—Test data on the comparative performance of three sizes of N. A. C. A. Roots type superchargers, two-geared centrifugal supercharges, and one vane-type supercharger have been analyzed and compared. The minimum power required to compress air by hypothetical superchargers of the geared centrifugal, vane, and Roots types operating under the same conditions and at the same efficiencies as the superchargers actually tested, but of sufficient capacity to compress 1 pound of air per second, formed the basis for this comparison. The adiabatic efficiency for each supercharger was also computed. For pressure differences up to 15 inches of mercury, the range of pressures investigated, the results obtained show that the Roots type supercharger requires less power than either of the other two types. At higher pressure differences the trend of the curves indicates that the centrifugal supercharger may require less power. As the discharge rate at which certain superchargers operate at minimum power is very limited, considerable saving in power can be effected by selecting the size of supercharger that is best fitted for the service required. A report will be prepared in the near future presenting the results of this investigation.

Supercharger modifications.—The manufacturer of the welded steel impellers which are intended for use in the Roots type supercharger has been unable to make delivery to date because of unexpected constructional difficulties. A sample steel impeller delivered at the laboratory showed that electric welding was feasible, but that great care was necessary to obtain a good weld between the impeller shell and the ribs and at the same time obtain the correct impeller contour without the necessity of excessive grinding. A process of forming and grinding the ribs before welding is now being investigated to overcome this difficulty. It is believed that these steel impellers in an aluminum case will give sufficient operating clearances at the temperatures obtained at high compression ratios to permit assembly and operation at low and medium compression ratios with small clearances. Should the clearances be excessive with steel impellers in an aluminum case at high operating temperatures the possibility of reducing the clearance by cooling the case will be considered.

Cooling of superchargers.—From both a thermodynamic and a mechanical point of view it is desirable that a supercharger operate in such a manner that the compression exponent n in the expression $P_1V_1^n = P_2V_2^n$ shall have the minimum practical value. The thermodynamic reasons are that it requires less power to compress a given weight of air with a low compression exponent and the delivery air temperatures are lower, which will result in an increase in the weight of the air delivered to the engine and, therefore, in an increase in engine power. The mechanical reasons are that the supercharger operates at a lower temperature, as a result of which the heat, stresses are reduced and the friction, clearance, and lubrication difficulties are decreased. The theoretical power required to compress 1 pound of air per second from atmospheric pressure to 29.92 inches of mercury for altitudes from 0 to 50,000 feet, using compression exponents of 1, 1.1, 1.2, 1.3, 1.407, 1.5, 1.6, 1.7, 1.8, 1.9, and 2, has been computed. The temperatures of the discharge air for these conditions have also been computed. It was found that under standard atmospheric conditions a supercharger with a compression exponent of 1.24 would maintain a constant temperature in the air discharged up to about 36,000 feet, i. e., to the isothermal atmosphere. It was also found that a reduction of the compression exponent from the usual values to 1.24 would reduce the temperatures of the air discharged sufficiently to make possible a gain of approximately 50 horsepower on a supercharged Liberty engine at a critical altitude of 22,000 feet.

Effect of supercharger capacity on performance.—Tests to determine the effect of supercharger capacity on performance have been completed on a modified DH–4 airplane. During these tests measurements were obtained from which the high speed and climb performance of the airplane could be computed for the supercharged and unsupercharged flights. Four different rates of air delivery were obtained in these tests by driving an N. A. C. A. Model II Roots-type supercharger at 3, 2.4, 1.957, and 1.615 times engine speed. The power output of the engine was measured by a calibrated propeller. The quantity of air inducted was measured by the supercharger, which had previously been calibrated in the laboratory. The fuel consumption was measured by a Venturi type fuel-flow meter. In addition, the usual measurements for computing airplane performance were obtained. A report presenting the results of this investigation is now being prepared for publication.

Hub dynamometer.—A propeller hub dynamometer employing hydraulic pressures to transmit engine torque to a photographic recording apparatus is being designed. This type of dynamometer has been selected from several different types as the most suitable type for the measurement of power during flight. Considerable experimental and analytical work has been done on the component parts of the dynamometer. The torque transmitting and recording apparatus will be carried in a spinner. The hub dynamometer will be light in weight, compact, and easily adapted to performance testing of engines up to 400 horsepower in flight.

Fuel flow meter.—An experimental Venturi-type fuel-flow meter has been used on a number of supercharged and unsupercharged flights. Some difficulty has been experienced because of failure of the pressure-recording mechanism. Changes are now being made to eliminate this difficulty.

Effect of cowling on cylinder-head temperatures.—Measurements have been obtained of the temperatures of the cylinder heads, barrels, and fins of a Wright J–5 air-cooled engine without cowling and with three different amounts of cowling. These tests were conducted in conjunction with aerodynamic tests made in the propeller research tunnel on the same cowlings. Sixty-nine thermocouples were used for obtaining these temperatures. Forty-seven thermocouples were installed on cylinder No. 1, which gave a sufficient number of points to predict the approximate temperature of any other point on the cylinder. The remain ng 22 thermocouples were attached to the other eight cylinders at the front and rear spark-plug bosses of each cylinder and below the top fin on several of these cylinders, thus giving sufficient information to check the engine performance under different conditions of cooling. During these tests measurements were also obtained of the power developed, manifold depression, oil-inlet and oil-outlet temperatures, carburetor air temperatures, atmospheric temperature, barometric pressure, air speed, and fuel consumption. For the first series of tests no cowling was used on any of the cylinders, for the second series of tests the cowling covered about one-third of each cylinder, and for the third series of tests the cowling covered about two-thirds of each cylinder. The fourth cowling tested was faired over the top of the cylinders and permitted the air to flow inside the cowling and around the cylinders and cylinder heads. The test data were taken at full throttle conditions at air speeds of 60, 80, and 100 miles per hour. The data for the four cowlings tested have been computed and plotted. A general examination of the test data collected to date shows that the cylinder-head temperatures were highest on the uncowled engine and lowest on the two-thirds-cowled engine. The temperatures on the lower parts of the cylinder barrel were lowest on the uncowled engine and highest on the two-thirds-cowled engine. The most uniform temperatures were obtained with the engine one-third cowled.

Effect of fuel consumption on cylinder temperatures.—Tests have been completed on a J–5 engine in the committee's propeller research tunnel in which the effect of fuel consumption on cylinder-head, barrel, and fin temperatures and on engine power were determined. The instruments and equipment used were the same as those used in the cowling tests. All measurements were taken at full-throttle conditions with air speeds of approximately 80 miles per hour. Six different mixture conditions were obtained by using jet sizes from No. 46 to No. 51, inclusive. A large reduction in cylinder temperatures was obtained by using rich mixtures. The data obtained in these tests will be analyzed and published.

Cooling efficiency of air-cooled cylinders.—An investigation has recently been started to determine the fundamental factors governing the cooling of finned surfaces. This investigation will consist primarily of determining the effects of pitch, length, and shape of fins on the cooling efficiency.

Completed investigations.—Two investigations reported as completed last year have been published this year under the titles "A Preliminary Investigation of Supercharging an Air-Cooled Engine in Flight" and "The Comparative Performance of Roots Type Aircraft Engine Superchargers as Affected by Change in Impeller Speed and Displacement."

A report has been prepared for publication on the results of tests previously conducted to determine the actual variation in power with altitude of an unsupercharged Liberty 12 engine. The engine torque in these tests was measured with a Bendemann hub dynamometer. The experimental results obtained were compared with those calculated by correcting the sea-level power of the engine for temperature and pressure at altitude. The results substantiate the theoretical relation of brake horsepower to altitude based on the correction of sea-level indicated horsepower for changes in atmospheric temperature and pressure with the subsequent deduction of friction horsepower corrected for altitude.

A theoretical investigation has been completed and the results prepared for publication on the possibility of using mechanically operated discharge valves in conjunction with a manually operated intake control for improving the performance of N. A. C. A. Roots type superchargers. Both oscillating and rotating valves were considered in this analysis, but the rotating valves were selected as the most desirable for high-speed superchargers. The intake control limits the quantity of air compressed to engine requirements by permitting the excess air to escape from the compression chamber before compression begins. The results of the analysis on these valves indicate that a power saving of approximately 26 per cent may be obtained at a critical altitude of 20,000 feet. The valves have the disadvantage of increasing the weight and of adding a high-speed mechanism to a supercharger of otherwise simple design.

ENGINE ANALYSIS—*Fuel-vapor pressure.*—The test data previously obtained for the effect of temperatures from 175° to 900° F. on the vapor pressures of several fuels have been analyzed.

Comparison of this data with the experimental data of Regnault, Ramsey, and Young indicates that the vapor pressures were lowered by the effect of catalytic or other action of the iron of the bomb and the nitrogen above the liquid. A pressure calibration curve has been established for these effects by means of the classical data available for the unmixed liquids. The experimental results show that the vapor pressures of the liquids tested increased rapidly with temperature, and that the rate of increase became greater as the fuel vapors approached their critical temperature. Beyond the critical temperature the rate of pressure increase was constant except at one or more temperatures for certain fuel vapors in which chemical changes took place. Permanent gases were generated in the case of some of the liquids to such an extent that the liquid removed from the bomb was materially different from that placed in it. Analysis indicates that the vapor pressure of a fuel is a quantitative measurement of the physical preparation of the fuel for autoignition in a fuel-injection engine. A report covering the analysis and the experimental data on gasoline, kerosene, Diesel fuel oil, ethyl alcohol, methyl alcohol, mixtures of methyl alcohol and gasoline, mixtures of benzol and gasoline, and an aircraft lubricating oil has been prepared for publication.

Analysis of oil-engine cycle efficiencies.—The performance of aircraft oil engines is dependent upon their over-all efficiency, which includes cycle, combustion, volumetric, mechanical, and cooling efficiencies. The cycle efficiency is of major importance because it determines the extent of the theoretical heat losses carried out by the exhaust gases. The engine cycle that should be used for aircraft oil engines is the dual cycle, a combination of constant-volume and constant-pressure combustion. This cycle, in comparison with the Otto cycle for the same power output, reduces the theoretical weight per horsepower and increases the reliability.

The theoretical investigation of a number of factors controlling the actual cycle efficiencies of oil engines has been continued. The effects on the efficiency of oil engines working on the dual cycle of compression ratio, maximum cylinder pressure, air available for combustion, temperature of the inducted air, temperature and pressure of the residual exhaust gases, and point of cut-off are being determined. A series of calculations leading to the determination of the pressures, temperatures, and volumes at various points on the theoretical indicator card for a wide range of compression ratios and maximum cylinder pressures is being made. These calculations require the determination of the specific heats of the several cylinder gases involved at constant volume and at constant pressure up to the highest temperature of combustion and their effects on the pressure, temperature, and volume. It is also necessary to determine the effects on the same quantities of the Joule-Thomson effect, volumetric efficiencies versus compression ratio, the chemical composition and weight of the working mixture at the various points of the cycle, the quantity of fuel required for constant-volume and constant-pressure combustion, and of other factors. The completed results of this work will determine the theoretical compression ratios and maximum cylinder pressures at which aircraft oil engines should operate to obtain maximum performance for different aircraft services, and will enable the rapid determination of the cycle and combustion efficiencies of an oil engine when the usual test data are known.

An analysis of the specific heats of the gases of combustion as determined by three methods—first, by consideration of the theoretical heat content of the molecule due to its translational, vibrational, and rotational energy; second, by experiment involving the velocity of sound method; and third, by experiment involving the explosion method—has been completed. This analysis included studies of the work of Holborn and Henning, Pier, Bjerrum, and Partington and Shilling, and the application of the Einstein and Nernst-Lindeman energy functions. The gases considered were H_2O, CO_2, N_2, O_2, H_2, CO, and air. After extended analysis of the reliable data, curves have been prepared representing the variation of the specific heats of the above gases with temperature from 0° to 3,000° C. The equations for these curves have been derived, evaluated for each 100° C. from 0° to 3,000° C., tabulated, and plotted for the instantaneous and mean specific heats at constant volume and constant pressure. The equations for instantaneous gamma, which is the ratio of the instantaneous specific heat at constant pressure to that at constant volume, have been derived, evaluated for each 100° C. from 0° to

3,000° C., tabulated, and plotted. The equations for mean gamma, where mean gamma between 0° C. and any temperature t° C. is equal to the mean value of instantaneous gamma between the temperature limits of 0° and t° C., have been derived, evaluated for each 100° C. from 0° to 3,000° C., tabulated, and plotted. A report covering this work is being prepared for publication.

The value of mean gamma between 32° F. and any temperature t° F. up to 5,400° F. has been calculated and plotted for explosion mixtures for the case of complete combustion, using fuel quantities per cycle of 2, 2.5, and 3.44×10^{-4} pounds, which correspond to 72 per cent, 37.6 per cent, and 0 per cent excess air, respectively. Further calculations and graphs are being made so that the value of mean gamma for the case of complete combustion of oxygen with carbon and hydrogen between 32° F. and any temperature t° F. up to 5,400° F. may be taken from a graph for any mixture of gases and for any excess air from 0 to 190 per cent. These graphs will greatly reduce the amount of work involved in calculating the value of mean gamma for any gas and fuel mixture between any two temperatures for the case of complete combustion.

Calculations of pressures, temperatures, and volumes at various points on the theoretical indicator card of oil engines working on the dual cycle, taking into account the actual constituents of the mixture and the variation of specific heat with temperature, have been made for the general case of no excess air, which has included to date a maximum cylinder pressure of 700 pounds per square inch, and compression ratios of 6.1, 8, 10, 12, 14, and 16.

Analysis of the results shows that a small change in the maximum temperature attained at the completion of constant-volume combustion causes a considerable change in the quantity of fuel burned at constant pressure, which changes the point of cut-off and therefore the cycle efficiency. More accurate calculations are being made to determine the exact quantity of fuel required for constant-volume combustion.

Calculations of pressures and temperatures have been made at 20 points on the expansion curve, first by using a constant value of the exponent, and second by using the varying value of the exponent for adiabatic changes of state to determine the extent of error involved by using the constant value. It was reported in the preceding annual report that the negative work found by using a constant value of the exponent in the calculations of the compression curve was less than that obtained by using a varying exponent, although the difference was small; i. e., the greatest variation in pressure being about 0.5 per cent. It was expected that this error would be greater on the expansion curve on account of the increase of the specific heats of gases with temperature. The error for the expansion stroke was found to be greater as expected, the greatest variation in the pressure being of the order of 1 per cent. Since the true pressures and temperatures for both the compression and expansion strokes are higher than those determined by using a constant value of the exponent, the difference in the network of the cycle as calculated by the two methods is small, being less than 0.5 per cent.

Injection valves.—One of the many problems involved in the successful operation of aircraft oil engines is that of the fuel-injection system. For hydraulic pressure systems the injection valves may be automatic or mechanically operated. The successful design of an efficient injection valve requires a study of the effects of weight, movement, and operating forces on all its parts. A practical and theoretical study of the effects of these factors on the injection lag, spray, cut-off, spray atomization and distribution, and fuel delivery rates is being made. The physical equation for the opening motion of an automatic injection valve with a stem which is held to its seat by a helical spring has been evaluated to show the effects of weight and operating forces on the lift of the valve stem for values of these factors generally met in practice. The rate of change of these effects has also been obtained and the results plotted. The investigation of the movement of a valve stem which is held to its seat by a diaphragm has been started.

Maximum-cylinder-pressure indicator.—The performance of aircraft oil engines depends to a large extent on the magnitude of the pressures and temperatures developed in the combustion chamber by the combustion of the fuel. Various instruments have been constructed to record the maximum cylinder pressures developed, but most of them are too complicated and expensive for general use and the pressures recorded are usually considerably lower than the actual pressures. A simple and inexpensive maximum-cylinder-pressure indicator has been developed having only one moving part, a small diaphragm weighing 0.0004 pound, which has a movement of only 0.0025 inch A report describing the operation and construction of this indicator is being prepared for publication.

BUREAU OF STANDARDS

Supercharging of aircraft engines.—During preliminary tests of a Curtiss D-12 engine equipped with a gear-driven centrifugal supercharger having a rated altitude of 20,000 feet, the supercharger impeller bearings failed and the impeller drive shaft was broken as a result. Since replacements were not available, the tests were discontinued pending the possible redesign of the supercharger.

In the tests made two years ago of a Curtiss D-12 engine and of a Liberty 12 engine under ideal supercharging conditions—that is, with air supplied to the carburetor at sea-level pressure while the pressure at the exhaust ports is reduced to the standard pressure corresponding to any desired altitude—the air-cooling box installed when the altitude chamber was originally built was found to have inadequate cooling capacity. It was therefore necessary to operate both engines at part throttle above an altitude of 10,000 feet. A new air-cooling box, having several times the capacity of the old box, has been designed and constructed. Other improvements have been made in the test equipment, and the test of the Curtiss D-12 engine under ideal supercharging conditions will be completed operating at full throttle up to at least 25,000 feet.

Phenomena of combustion.—Further studies of the gaseous explosive reaction at constant pressure using mixtures of carbon monoxide, oxygen, and argon confirm the conclusion, stated in Technical Report No. 280, that the effect of an inert gas on the reaction rate depends on its thermal properties. The similarity of the results obtained with helium and with argon suggests that the important factor is the molecular heat rather than the thermal conductivity, as previously believed. A report on the kinetics of compos te fuels soon to be published by the National Advisory Committee for Aeronautics shows that it is possible, from the velocity coefficients of carbon monoxide and methane, to predict the flame velocity of any composite fuel made up of these ingredients for any mixture ratio of fuel and oxygen which will ignite. When hydrogen is a component of the fuel, analysis of the data becomes more difficult, although of unusual practical interest.

Combustion in an engine cylinder.—A single-cylinder engine has been provided with a special water-cooled cylinder head having a large number of quartz windows symmetrically distributed over the combustion space. Light from the explosion passes through these windows and, by means of a lens, is focussed on a stroboscope, consisting of two rotating disks driven by the engine crankshaft. Holes in the disks permit a momentary view of the windows at the same point in successive cycles. By making observations at different points in the cycle the progress of the flame may be charted and the effect of operating conditions and fuel composition on flame movement and velocity may be studied.

Pressures and temperatures in an aircraft engine.—A review of published work on this subject is being made in order to summarize the methods, results, and conclusions of previous investigations. Measurements of piston, cylinder, and valve temperatures in different types of engines and over a considerable range of operating conditions have been reported. A variety of indicators for determining cylinder pressures have been described, but very few aircraft engine indicator diagrams complete with data as to the conditions under which they were taken have been found in the literature. A single-cylinder Liberty test engine, provided with means for varying the compression ratio and adapted for operation under approximate altitude conditions, has been set up and will be used in obtaining indicator diagrams under a wide range of operating conditions.

Automatic altitude control.—At the request of the Navy an experimental multiplied-pressure pump of the sort proposed in Technical Note No. 108 of the National Advisory Committee was built and tested under approximate altitude conditions. This gave satisfactory performance, but a lighter and more compact pump was required for flight test. Two-cylinder models suitable for installation on the Curtiss D-12 engine and on the Wasp engine have been designed. One of the latter will be constructed and fitted to operate the carburetor altitude control on a Navy pursuit airplane.

Gaseous fuel carburetor.—A report has been made to the Navy Department describing and giving design data for a simple type of gas-and-air mixing valve which was found to operate satisfactorily either in series or in parallel with a conventional gasoline carburetor. The report included a detailed comparison of the performance in an engine of city illuminating gas, aviation gasoline, and mixtures of the two fuels. The illuminating gas gave somewhat less power than the aviation gasoline, but later engine tests using gaseous fuels of higher heating value showed approximately the same power and economy with gas as with gasoline.

Fuels for high-compression engines.—For routine testing of fuels, the Bureau of Standards has continued to use as a criterion of relative antiknock value the maximum power which different fuels will develop in a single-cylinder Liberty test engine without excessive detonation as judged by ear. Ethyl benzene appears to be about 50 per cent more effective than motor benzol in reducing the tendency of gasoline to knock. It has the further advantage of a low freezing point.

In the work undertaken for the Navy on the development of a bomb method for comparing the antiknock characteristics of aviation gasolines, changing the shape of the bomb failed to give more reproducible results for knock intensity, and attention was centered on the tendency of fuels to autoignite. Autoignition in the bomb used takes place an appreciable time after liquid fuel is injected into the preheated air with which the bomb is filled. The results are conveniently expressed in the form of curves showing the time required for the charge to ignite at different bomb temperatures. Such curves, of course, do not give the temperature of the charge which ignites after a given time lag, but further data may permit some correlation between antiknock value and these ignition plots.

Lubrication under starting conditions.—From measurements on the rate of flow of about 40 commercial lubricating oils through the oil passages of a Wright J-4 engine there has been obtained a characteristic curve by means of which the oil flow under specified low-temperature starting conditions can be predicted from its viscosity as determined in the laboratory at the ice point, provided the oil is a simple viscous liquid. The flow of oils which are plastic at the temperature of test can not be predicted in advance. The earlier work on the flow of aircraft-engine oils at low temperatures is not yet available in report form.

Type testing of commercial engines.—The Bureau of Standards cooperated with representatives of the Army Air Corps and the Navy Department in formulating tentative requirements for the type testing of commercial aircraft engines. The present regulations of the Department of Commerce (Aeronautics Bulletin No. 14, pp. 40–42) state that engines which have passed the regular endurance tests of the Army Air Corps or the Navy Department will be approved and that other engines submitted for approval will be tested at the Bureau of Standards. Three engines have been tested at the bureau under the present regulations and two of these have been approved.

NEW ENGINE TYPES

The most notable development of the year was the production by the Packard Motor Car Co. of an air-cooled radial engine operating with fuel injection on the Diesel principle. This engine has been fitted in an airplane and used in several flights. It is the first lightweight Diesel engine to be used in the flight of an airplane. The builders have withheld practically all definite information regarding this engine, but it is reported that it develops about 200 horsepower and weighs about 3 pounds per horsepower.

A further feature of the development of the past year has been the many new types of air-cooled engines which were produced for use in civil airplanes. These have been mainly of the radial type. Even with these new types of engines in use by both the military and commercial activities the deliveries to the commercial concerns have exceeded those to the Army and Navy.

The Air Commerce Regulations require that the engines used in interstate air commerce shall be of types which have been approved after suitable tests. A large proportion of the new types of engines have been submitted for the purpose of obtaining approved-type certificates. The Department of Commerce has issued approved-type certificates for 10 engines, and many other engines are awaiting tests which, of course, are delayed on account of the number on hand.

The stocks of engines of medium power (less than 150 horsepower) which were carried over from war-time production are nearly exhausted. The prices of new engines of the types which have recently been developed are usually many times the prices recently charged for the war-time surplus engines. This has led to attempts to produce cheaper engines by the modification of engines of types which exist in considerable numbers as war-time surplus but which are not suitable for use in their original form. However, there are many difficulties in design and construction introduced by the attempt to convert an existing engine into something quite different.

Air-cooled engines.—Both the Army Air Corps and the Bureau of Aeronautics of the Navy have been interested in the further development of air-cooled engines for service use. Many of these engines have been adopted for use in commercial airplanes.

The Curtiss Aeroplane & Motor Co. has produced the "Chieftain" (H–1640), which develops 600 horsepower at 2,200 r. p. m. This is the 12-cyclinder 2-row radial engine referred to in last year's report as the "Hex" engine. The crank shaft has two throws, each working from six cylinders. By this arrangement the over-all diameter of the engine is reduced and the counterweight which would be required on a single-throw crank shaft is eliminated. This engine is still under development for use as a military engine, but has obtained an approved-type certificate for commercial use.

The Curtiss Co. has also introduced the Challenger (R–600) engine, which develops 170 horsepower at 1,800 r. p. m. This engine is a 2-row 6-cylinder air-cooled engine with a 2-throw crank shaft and three cylinders working on each throw. The advantages expected are the same as in the Chieftain. This engine also has received an approved-type certificate for commercial use.

The Pratt & Whitney "Wasp" 9-cylinder radial engine, rated at 410 horsepower at 1,900 r. p. m., which was made standard equipment for service airplanes of the Navy more than a year ago, has been used quite extensively in commercial service. The operators of commercial air lines found that a greater reserve of power was necessary to enable them to keep to schedules in flying passengers and mail. Consequently engines of considerably greater power than were originally fitted have been installed in many such airplanes. The Wasp engine has been quite largely adopted for this purpose.

The Pratt & Whitney Co. has now brought out a "Series B Wasp" engine which is rated at 450 horsepower at 2,100 r. p. m. By resorting to doped fuels this engine is reported to have developed 600 horsepower at 2,300 r. p. m.

The Pratt & Whitney "Hornet," rated at 525 horsepower at 1,900 r. p. m. has been standardized by the Bureau of Aeronautics of the Navy Department and by the Army Air Corps. It has also been adopted by the Boeing Air Mail. This engine is being built in production quantities.

The Wright Aeronautical Corporation "Cyclone" engine (R–1750), a 9-cylinder radial rated at 525 horsepower at 1,900 r. p. m., has been standardized by the Bureau of Aeronautics of the Navy Department and by the Army Air Corps and is being built in production quantities.

The Wright Aeronautical Corporation has brought out a new series of radial air-cooled engines, the J–6. These engines are made in three sizes—5 cylinders developing about 160 horsepower, 7 cylinders developing about 220 horsepower, and 9 cylinders developing about 300 horsepower, all at 2,000 r. p. m. In these engines the attempt has been made to have a maximum of parts interchangeable and the same cylinders are used. These engines are still under development as far as service use is concerned.

The Wright Corporation is still at work on the development of the 12-cylinder inverted "Vee" air-cooled engine of approximately 1,500-cubic-inch-piston displacement, which was mentioned in last year's report. This engine is intended to develop 600 horsepower at 2,500 r. p. m.

The 9-cylinder Wright Whirlwind engine continues in general favor in spite of the tendency to use higher powers in many airplanes. The reduction in cost resulting from a long series production is also causing it to be used more widely where the medium-power engines would be expected.

The 24-cylinder "X" type air-cooled engine constructed by the Allison Engineering Co. for the Army Air Corps and intended to develop approximately 1,400 horsepower is still under development.

Service tests and development of the experimental inverted air-cooled Liberty engines built by the Allison Engineering Co. under the supervision of the Army Air Corps have not yet been completed.

Water-cooled engines.—Development work continues on the Curtiss V–1550 engines which are being sponsored by the Army Air Corps. These engines, which are of the 12-cylinder "Vee" type, have been given the name "Conqueror" and are being produced in both geared and direct drive forms. In the endeavor to obtain even more power from them than their present 600 horsepower at 2,400 r. p. m. superchargers are being resorted to. Both the gear-driven centrifugal and the gear-driven Roots–N. A. C. A. types of supercharger are being used. It is expected to obtain a substantial increase in power at all altitudes. The weight of the direct-drive Conqueror (V–1550) is about 740 pounds. The geared model (GV–1550) weighs about 835 pounds. This model has developed 625 horsepower at 2,500 r. p. m.

Both the geared and direct drive models of the Conqueror have been granted approved-type certificates by the Department of Commerce and rated at 600 horsepower at 2,400 r. p. m.

Development work continues on the series of Packard water-cooled engines bearing the designations A–1500 and A–2500 which have been given experimental and service tests by the Army Air Corps. The 3A–1500 is available in both inverted direct-drive model and in upright geared drive. It is rated at 600 horsepower at 2,500 r. p. m.

The 3A–2500 on one test was found to develop 770 horsepower at 2,000 r. p. m. A further development of this engine (4A–2500) using a supercharger develops approximately 950 horsepower at 2,200 r. p. m.

Superchargers.—In the endeavor to obtain a maximum of power and to maintain power to altitudes superchargers are being generally applied to existing and new models of engines. There is no longer hesitation in the application of a supercharger to either air-cooled or water-cooled engines. Both the Roots–N. A. C. A. and the centrifugal type of supercharger have been successfully applied to both types of engines, while the possible application of the vane type of blower as a supercharger is being investigated. The use of superchargers is being borrowed from the military services for commercial applications just as the military engines have been borrowed.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

The present organization of the committee on materials for aircraft is as follows:

Dr. George K. Burgess, Bureau of Standards, chairman.
H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.
S. K. Colby, American Magnesium Corporation.
Warren E. Emley, Bureau of Standards.
Henry A. Gardner, Institute of Paint and Varnish Research.
Dr. H. W. Gillett, Bureau of Standards.
Lieut. C. B. Harper (C. C.), United States Navy.
Prof. George B. Haven, Massachusetts Institute of Technology.
C. H. Helms, National Advisory Committee for Aeronautics.
Zay Jeffries, Aluminum Co. of America.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
C. L. Ofenstein, Aeronautics Branch, Department of Commerce.
Capt. H. C. Richardson, United States Navy.
E. C. Smith, Central Alloy Steel Corporation.

G. W. Trayer, Forest Products Laboratory, Forest Service.
Starr Truscott, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.

In view of the increasing importance of steel and the welding of steel in aircraft structural design, it seemed desirable that a representative of the steel industry who would be familiar with the practical problems of steel construction be included in the membership of the materials committee. Mr. E. C. Smith was accordingly appointed a member with further assignment to the subcommittee on metals. During the past year Lieut. C. B. Harper has been appointed to membership to succeed Lieut. R. S. Barnaby, relieved, and Messrs. Emley, Helms, and Ofenstein have been appointed additional members.

FUNCTIONS

Following is a statement of the functions of the committee on materials for aircraft:

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.
2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigation of materials for aircraft in progress or proposed.
4. To direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development. Much of the research, especially in the development of light alloys, must necessarily be conducted by the manufacturers interested in the particular problems, and both the Aluminum Co. of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research for aircraft, four subcommittees have been formed, as follows:

Subcommittee on metals:
Dr. H. W. Gillett, Bureau of Standards, chairman.
Zay Jeffries, Aluminum Co. of America.
J. B. Johnson, matériel division, Army Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Central Alloy Steel Corporation.
Starr Truscott, National Advisory Committee for Aeronautics.
H. L. Whittemore, Bureau of Standards.

Subcommittee on woods and glues:
G. W. Trayer, Forest Products Laboratory, Forest Service, chairman.
H. S. Betts, Forest Service.
George W. Lewis (ex officio member).
H. L. Whittemore, Bureau of Standards.

Subcommittee on coverings, dopes, and protective coatings:
Henry A. Gardner, Institute of Paint and Varnish research, chairman.
Dr. W. Blum, Bureau of Standards.
Warren E. Emley, Bureau of Standards.
Prof. George B. Haven, Massachusetts Institute of Technology.
Isadore M. Jacobsohn, Bureau of Standards.
C. H. Helms, National Advisory Committee for Aeronautics.
George W. Lewis (ex officio member).
P. H. Walker, Bureau of Standards.
E. R. Weaver, Bureau of Standards.

Subcommittee on aircraft structures:

Starr Truscott, National Advisory Committee for Aeronautics, chairman.
Charles Ward Hall, Hall-Aluminum Aircraft Corporation.
Lieut. Lloyd Harrison, United States Navy.
G. W. Lewis (ex officio member).
Charles J. McCarthy, Chance Vought Corporation.
C. L. Ofenstein, Aeronautics Branch, Department of Commerce.
L. B. Tuckerman, Bureau of Standards.
John E. Younger, Matériel Division, Army Air Corps, Wright Field.

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics.

The Bureau of Aeronautics and the matériel division of the Air Corps, in connection with the operation of tests in their own laboratories, apportion and finance research problems on materials for aircraft to the Bureau of Standards, the Forest Products Laboratory, and the industrial research laboratories.

MEETINGS OF THE COMMITTEE

Meetings of the committee were held several times during the year to consider reports on the work being conducted by the subcommittees. Particular attention was given the continuation of work on the development of methods for protecting light alloys, particularly duralumin, from corrosion. This work was begun some years ago and has always formed a major subject for investigation.

SUBCOMMITTEE ON METALS

The Bureau of Standards conducts practically all the investigations on the properties of metals and their application to aircraft construction. These investigations are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. In some instances the manufacturers of materials which appear to have promise for use in aircraft cooperate with the Bureau of Standards in the investigation of these materials and occasionally a manufacturer presents the results of his own research work directly to the committee. Some of the more important investigations completed during the past year or now in progress are outlined below.

Intercrystalline embrittlement of sheet duralumin.—The results of earlier phases of the study of the behavior of sheet duralumin with respect to the tendency toward embrittlement under corrosive conditions have been summarized and issued during the year in the form of four Technical Notes of the National Advisory Committee, Nos. 282–285. These notes deal with (*a*) the practical aspects of the problem, (*b*) accelerated corrosion tests and the behavior of high-strength aluminum-alloy sheet of different compositions, (*c*) the effect of the treatment of duralumin on its susceptibility to embrittlement, and (*d*) the use of protective coatings.

Further work on the effect of heat treatment on the propensity of sheet duralumin to embrittlement by corrosion has confirmed the previous conclusion that heat treatment by quenching in cold water, rather than hot water or oil, and aging at room temperature imparts higher corrosion resistance to the material. With very thin material, however—for example 0.008 inch sheet—the corrosion resistance does not appear to be influenced very much by varying the heat treatment. "Alclad" duralumin, which according to laboratory corrosion and exposure tests is the most dependable of the materials of the duralumin type, should also be heat-treated in the manner just described in order to develop the highest degree of corrosion resistance. "Alclad" duralumin sheet which had been heat-treated by hot-water quenching has been found to show evidence of corrosive attack on cut edges.

A detailed study of the microstructure of duralumin after different types of heat treatment failed to show any definite relation between the degrees of susceptibility to intercrystalline corrosive attack and the visible microstructure. Evidently the tendency of the material in this regard is determined by the ultramicroscopic features. X-ray studies by the Laue method have been made of sheet duralumin in various conditions and after various degrees of corrosive attack. The conclusion was reached that this method of test can not be depended upon as a sure means for evaluating the propensity of this material toward intercrystalline embrittlement. This is contrary to the conclusion reached by some other workers in this field, such conclusions being based, however, on a very limited number of specimens.

The weather-exposure tests of sheet duralumin have been in progress for a little more than one year in Washington, D. C., and Hampton Roads, Va., and for about nine months at Coco Solo, Canal Zone. Tension specimens exposed to the weather are tested periodically and compared with similar specimens which have been stored in a *dry* atmosphere within sealed containers in the laboratory. After testing, all bars are examined microscopically for evidence of intercrystalline corrosive attack.

While the tests have not yet advanced sufficiently to permit final conclusions, comparison of the results brings out some interesting points. Fourteen-gauge sheet duralumin, heat-treated by cold-water quenching and aging at room temperature, when exposed in the bare state was unharmed after one year's exposure in Washington. Similar material lost about a quarter to a fifth of its ductility in one year at Hampton Roads and about the same in 4½ months at Coco Solo. Material of similar gauge, heat-treated by quenching in hot water or oil, is just starting to lose ductility after one year's exposure in Washington. Similar material has lost half its ductility and fallen considerably in tensile strength after one year's exposure at Hampton Roads or 4½ months' at Coco Solo.

Although visual examination of coated specimens at Washington and Hampton Roads indicates that many coatings are in excellent shape, tensile tests from the Hampton Roads and Coco Solo exposure tests of hot-water quenched and variously coated specimens show that only the Alclad coating and aluminum-sprayed coatings fully protect the metal under the conditions prevailing at these locations (sea air). Aluminum pigmented varnish and grease covered with aluminum powder stood up well for a while, but after 7½ months at Coco Solo and a year at Hampton Roads they, too, showed evidence of failure. No tensile results are yet available on the linseed oil-carbon black coating on hot-water quenched duralumin, which coating, according to the tests carried out by the subcommittee on protective coatings, is the most promising one of this type. The aluminized rubber-cement coatings have not shown up quite so well in exposure as they did in laboratory tests. Final conclusions must await longer exposure, however, and in any event they would seem to deserve consideration as priming coats.

The exposure tests indicate in general that for purely inland service cold-water-quenched room-temperature-aged duralumin with any nonmetallic coating that shows fair life by visual inspection, or even the bare material, should have satisfactory life. Salt mist on a broken-down coating or on bare material can, however, do much damage.

For seacoast work no nonmetallic coating has as yet proved reliable indefinitely. Cleaning and recoating as often as every six months would probably be required. For the combination of ease of cleaning and degree of protection grease with aluminum powder coating would appear to stand well toward the head of the coatings other than Alclad.

The indications of the exposure tests may be summed up as:

(1) Favoring Alclad or sprayed aluminum coatings for general use; and, for still further protection,

(2) Favoring *flexible* coatings such as the replaceable aluminized grease or perhaps carbon black in linseed oil (on the basis of the old Junkers airplane at Hampton Roads).

The exposure tests will be continued during the coming year.

Very thin sheet duralumin (0.008 inch) has shown a relatively very low corrosion resistance in exposure tests carried out in Washington. Varying the heat treatment does not very materially improve the corrosion-resistance of this material. Anodic surface oxidation and a greasing treatment (lanolin) protected this material for only a relatively short time. Frequent regreasing, at least every two months and probably once a month, would be required for perfect protection of this material in Washington. At Hampton Roads the attack was even more severe. Thin (0.010 inch) Alclad duralumin sheet exposed under the same conditions at Washington showed a very high degree of resistance during six months' exposure. The same material reheat treated, however, showed noticeably lower resistance than did the commercial sheet.

The scope of the laboratory corrosion tests during the year has been extended to include the effect of stress acting on the material simultaneously with corrosive attack. There is some reason to believe that duralumin under the stress conditions which obtain in service is more subject to the embrittling attack than unstressed material is. The effect of both static tensile stress and repeated flexural stress has been studied. For the latter, two machines of special design whereby the tension bar could be corroded by immersion at stated intervals while it was being repeatedly bent back and forth were built.

Static tensile stress increases the rate of intercrystalline attack. Repeated bending stress increases it still more, 10,000 pounds fiber stress in repeated bending accelerating the attack as much as 20,000 pounds in static tension. The acceleration of the attack is much more marked on hot-water-quenched than on cold-water-quenched duralumin. This behavior is consistent with the superior behavior of cold-water-quenched material in all other laboratory and exposure tests. Accelerated corrosion tests on the repeated flexure machine appear to give the bare material the most searching corrosion test yet possible in the laboratory. Alclad duralumin tested in this way has shown the highest resistance of all materials tested. Other types of coated specimens have not as yet been tested.

As a supplement to the exposure tests, a determination of the permeability to atmospheric moisture of spar varnish, both plain and aluminum-pigmented, has been made. The results confirm in all respects the results of exposure tests as to the advantage to be gained by incorporating aluminum powder into a varnish to be used for out-of-doors exposure.

In the search for light alloys suitable for aircraft, considerable attention has been given to beryllium, which is not at present available commercially. If the modulus of elasticity of this metal is as high as some of the values reported, it should be particularly suitable for long columns. Although this metal is very expensive, it might be advisable to use it in aircraft if, for example, the cruising radius could thereby be increased 50 per cent.

In addition to the other publications reported by this subcommittee attention is invited to the recent circular of the Bureau of Standards, No. 346, Light Metals and Alloys—Aluminum and Magnesium. This publication assembles much information of value to aircraft designers and builders.

High-speed fatigue testing.—Work with the high-speed fatigue testing machine has continued. As was reported last year, the method of supporting the specimen in the machine has been changed from a pivot support to an air-jet support, thus freeing the specimen wholly from any possible longitudinal restraint due to the pivots which might introduce adventitious stresses.

The change from pivot support to air-jet support of the specimen has resulted in greater uniformity of the test results and has practically eliminated machine trouble. A consistent series of tests on duralumin to 300,000,000 alternations of stress has been completed. It is felt that with the changes which have been made in the machine the design is now satisfactory for the frequencies used (approximately 200 to 600 cycles per second). Three new machines have been built and the battery of four are now in continuous operation.

The discrepancy between results obtained in the high-speed machine and those previously obtained in the low-speed (1,000 to 2,000 revolutions per minute) crank-driven machines has not yet been explained. The design of a machine to close the gap in frequencies (200 per second to 20 per second) between the two types of machines has been investigated but has not been satisfactorily worked out. Although the discrepancy is still unexplained, the consistency of the results on the high-speed machines justifies their use for comparative tests of different materials. The results of these comparative tests may help to explain the discrepancy.

Material has been obtained and tests have been started to compare the endurance of 14 different light alloys of both aluminum and magnesium bases.

Low-frequency flexural fatigue of Alclad duralumin and duralumin.—Alclad duralumin has been studied in the low-frequency machines up to a life of 100,000,000 cycles, at which it withstands an indicated stress of over 10,000 pounds per square inch, or more than four times the so-called yield point, far above the proportional limit of the pure aluminum coating and not far below its tensile strength. At very high stresses, far above the tensile strength of the coating, the coating becomes dulled and contains tiny checks or cracks, which, however, do not at once propagate through the specimen as similar surface cracks would in an all-duralumin specimen. This behavior gives reason to expect that when the surface is dented or scratched the relative endurance properties of Alclad duralumin will show a quite favorable comparison to duralumin, and experiments along this line, which are scheduled, are awaited with interest.

The machines being used are not suitable for stress-corrosion studies and for that angle of the problem the special machines mentioned above under the subject of intercrystalline embrittlement of sheet duralumin will have to be used.

SUBCOMMITTEE ON WOODS AND GLUES

The Forest Products Laboratory of the Department of Agriculture conducts practically all the investigations on the application of woods and glues to aircraft construction. These investigations are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics.

The steady increase in the use of metal in the parts of airplanes previously made of wood and the tendency toward all-metal construction is leading to a lessening in the need for additional data on woods and glues. However, wood will undoubtedly be used for some time to come. Attention is therefore being directed rather to the completion of work which has been under way than to the initiation of new projects.

The more important investigations in progress during the last year are described below.

The lateral buckling and twisting of deep beams.—The investigation of this subject was undertaken at the request of the Bureau of Aeronautics of the Navy Department in order to obtain information as to the maximum loads which could be carried by wing beams under varying conditions of loading and fixity. For some years a series of studies on the strength of beams has been in progress. These have included researches into the behavior of continuous beams and into the design of detailed parts of various types of beams.

Over 100 beams have been tested and the results have been compared with all the available formulas for rigidity and strength. The values computed by the formulas developed by Griffith and Taylor agree fairly well with the experimental values obtained with some cross sections.

Among the objects of the investigation has been the determination of the influence of form of cross section on the torsional stiffness of the beams. The computation of the torsional properties of bars having irregular sections is very complicated and presents many difficulties. A method using soap bubbles has been applied to this work and empirical formulas have been developed which have been used satisfactorily for some sections.

The bearing strength of wood under bolts, washers, and fittings.—The purpose of this investigation was to determine the allowable bearing strength of wood under bolts subjected to loads acting at various angles to the grain, the allowable distance between bolts, the influence of crossbolts, and the combined action of bolts of different diameters, the allowable bearing stresses under washers, fittings, etc. A series of progressive investigations was carried out in which the various phases of the problem were covered in detail. A report summarizing the work was made to the Navy Department and has been published by the National Advisory Committee for Aeronautics as Technical Note No. 296.

The water resistance of glues.—One of the subjects which has engaged considerable attention has been the resistance of the glues used in the manufacture of plywood to deterioration as a result of the absorbing of moisture. In order to determine the properties of the glues, films of glue alone were produced and were studied to determine the effect of various compositions and treatments on their permanance. This work is now being extended to tests of wood panels consisting of plywood and larger pieces.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

Much of the work on the development of coverings, dopes, and protective coatings is carried out at the Bureau of Standards, since in many cases it involves cooperation with the work of the subcommittee on metals. Investigations are also carried out by the exposure of test panels at the United States naval air stations at Hampton Roads, Va., and Coco Solo, Canal Zone. Exposure tests were also made on the roof of the laboratory of Mr. H. A. Gardner.

Some of the more important investigations in progress during the last year are outlined below.

Gas-cell fabrics.—This investigation appears to be nearing a successful conclusion. A substitute for goldbeater's skin gas-cell fabric has been made in large quantities. About 1,700 square yards were made on one order and fabricated into a gas cell for the *Los Angeles* at the Naval Aircraft Factory. The weight of this fabric unvarnished was 4 ounces per square yard and varnished, 4.3 ounces per square yard. This is slightly less than the weight of corresponding fabrics made with goldbeater's skin. The permeability obtained is about one-tenth liter per square meter in 24 hours, and some specimens showed practically no permeability. Laboratory tests showed that the endurance of this fabric is very great and that it retained its flexibility and permeability over an extended period. However, only service tests will tell how it really compares with goldbeater's-skin fabric. This fabric consists of a light and strong cotton cloth to which there is applied a thin coat of rubber and then successive coats of a mixture of viscose and latex. After drying the coatings the complete fabric is treated to revert the viscose.

A gas cell has been made from a fabric consisting of the usual light cotton cloth with spread rubber to which there has been cemented a layer of cellophane, which has greater flexibility and elasticity than the usual product. This cell will be installed in the *Los Angeles* for service test.

Coatings for duralumin to prevent corrosion.—The exposure tests at the naval air station at Hampton Roads, which have continued for about two years, show that the protection given to duralumin by linseed oil paints of the iron oxide, zinc chromate, or carbon black types are practically perfect. These coatings show no flaking or cracking such as is often observed with varnish or lacquer. Aluminum pigmented paints are also satisfactory, but the best coating of all seems to be carbon black or lampblack in linseed oil. Unfortunately paints of this type are naturally slow in drying. It has been found that the drying can be very much accelerated by the use of ultraviolet lights in the painting room or in the baking oven. In the latter case drying can be accomplished in about one hour. Apparently this method of accelerating the drying does not affect the durability of the paint. The application of such paints in "flat" surface films allows the use of aluminum finishing coats where the latter is desired.

Many new quick drying coatings based on synthetic resins are now being developed. These are being studied, as they appear to offer great promise as materials for aircraft finishes.

The anodic treatment of duralumin continues to be used and apparently has demonstrated a definite effect in improving the corrosion-resisting properties of material to which it has been applied. The process is also being used to provide a better surface for paints or further coatings. The use of a grease over the anodic coating gives very much better results than the plain coating. However, it has been found that the use of lanolin for this purpose can not be recommended as it takes up moisture from the air and rather assists than protects against corrosion. A very good grease coating can be made from vaseline by grinding in 5 per cent of zinc chromate. This coating has a yellow color and when the color disappears from the surface it gives a clear indication that the coating should be renewed.

A report on Representative Coatings for Duralumin and Other Aircraft Alloys, by Mr. H. A. Gardner, was issued as Circular No. 330, June, 1928, Scientific Section, American Paint and Varnish Association.

The method of protecting duralumin against corrosion by the application of a thin coat of pure aluminum has now been given thorough tests both experimentally and in service. The duralumin sheets protected on both sides by this method and supplied by the Aluminum

Co. of America as "Alclad" duralumin have been remarkably successful in resisting corrosion in service. Apparently this material has demonstrated its suitability for the purpose and may be accepted as a standard protective coating. The increase in the use of duralumin due to the introduction of this coating which was predicted last year appears to have taken place.

The success of the pure aluminum coating in preventing corrosion of duralumin has led to its application to other of the aluminum alloys with equally successful results. Tubing has not yet been produced using this method of protection, but the possibilities of this application are being investigated.

The exposure tests on protective coatings for duralumin are being continued. Only by carrying out a lengthy series of these tests in various localities will it be possible to determine the suitability of the various coatings for use in different services and localities. It has already been found that exposure at Coco Solo, Canal Zone, is a much more severe test of a protective coating than an exposure of the same time at Hampton Roads, Va.

Airplane dopes.—Experiments on airplane dopes are being continued and include the older forms and the newer semipigmented dopes. Heretofore the determination of the durability of an airplane dope has required the exposure of test panels for periods of from two to six months. A method of accelerating the testing of these panels has been developed which appears to give results comparable to three months' exposure on the roof within a period of 100 hours.

Substitute for silk parachute cloth.—American manufacturers of silk cloth have become interested in the possibility of supplying domestic-woven material for use in the manufacture of parachutes. Many samples of domestic-woven silk cloths which might be suitable for this purpose have been submitted. These have been tested and criticized. The manufacturers are now working in cooperation with the Bureau of Standards and other governmental agencies in the endeavor to develop a specification for silk parachute cloth which will be satisfactory to both War and Navy Departments. Such a cloth will also be suitable for use in parachutes for commercial work.

Work on the development of a substitute for silk cloth has been continued, but, as was related in the report of the committee last year, it has been found that domestic yarns with the necessary properties are difficult to obtain. It finally became necessary to make the yarn at the Bureau of Standards. Although the manufacture of the yarn is not yet complete, preparations for its treatment are being made. Further experiments have been made on the mercerization in the piece of lightweight cotton cloth. These experiments are not yet completed but it has been concluded that the cloth woven from yarns mercerized according to the methods which have been developed should approximate the required qualities.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

The Bureau of Standards conducts practically all the investigations under the cognizance of this subcommittee. These are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. Some of the more important investigations in progress or completed during the past year are outlined below.

Welded joints.—In view of the increasing interest in metal construction, the committee has endeavored to obtain information on the properties of welds, particularly the metallurgical and fatigue properties. Tests on butt welds made in sheets of duralumin, carbon steel, and chrome-vanadium steel, in four different thicknesses and by three different processes (atomic hydrogen, oxyacetylene, and electric arc) have been completed. The results show that sound welds by any of the three processes have tensile properties somewhat lower than the unwelded material. In the case of duralumin the strength is materially increased by heat treatment followed by cold working consisting of a reduction in thickness of approximately 10 per cent by hammering.

The properties of the adjacent sheet material were altered least by atomic hydrogen welding and altered most by oxyacetylene welding.

Alternating-stress tests in the flexural-fatigue machines were carried to approximately 5,000,000 alternations of stress. The comparison with unwelded sheet was made by testing both specimens with the same throw of the crank arm. Because of the greater thickness of the material in the weld this gave a higher nominal but a lower actual stress in the weld material. The tests indicated that the fatigue resistance of the welds as structures was not much lower than that of the unwelded sheet.

Strength of flat plates.—This investigation of the column strength of flat plates of nickel, duralumin, stainless steel, and Monel metal was undertaken because of the increasing use of structures in which the shell plating is required to act as a compression member carrying all or part of the load. Very little information existed as to the manner in which such loads were carried, and as a preliminary step toward the obtaining of such information the column strengths of flat plates of the different materials were determined. The effect of variations in width alone was considered. The plates were always flat, and, while the edges were fixed in position, they were not fixed in direction.

The value given by the theoretical equation for the buckling stress corresponds to the stress at which experimentally the plate begins to buckle. In the plates tested the maximum deflections at the theoretical buckling stresses varied from about 0.04 inch for the narrower specimens to about 0.07 inch for the wider specimens.

The maximum loads were generally higher than the theoretical buckling loads. This was especially true of the wider and thinner specimens, for which the theoretical buckling stresses are small compared to the proportional limits of the materials. Both the maximum loads and loads producing permanent deformation seem to depend on the proportional limits of the materials as well as on the elastic constants. In other words, after buckling begins the loads and deflections of the plate can be further increased until permanent deformation takes place.

The average maximum stress was calculated for each plate by dividing the maximum load by the area of the section. Curves based on these maximum stresses were drawn for plates varying in width from 4 to 24 inches and in thickness from 0.015 inch to 0.100 inch. One set of curves may be used for duralumin with a modulus of elasticity of about 10,000,000 pounds per square inch and proportional limit between 35,000 and 40,000 pounds per square inch. Another set of curves is for iron, Monel metal, or nickel, with modulus of elasticity between 24,000,000 and 28,000,000 pounds per sqaure inch and proportional limit between 20,000 and 30,000 pounds per square inch.

The form of the buckled plates was generally as predicted by the theory; i. e., the number of half waves in the length of the buckled plate was in most cases equal to the nearest whole number to the ratio of the length to the width.

Form factors for tubing of duralumin and steel under combined column and beam loads.—This research was undertaken to increase the amount of information available as to the loads which could be sustained by steel and duralumin tubing when used either in the fuselage or other structure of an airplane. So far the tests on one size of duralumin tubing and three sizes of chrome-molybdenum tubing have been completed, and curves for the use of the designer have been prepared for one size of each material.

A characteristic difference has been noted between duralumin and chrome-molybdenum tubing. For duralumin tubing the modulus of rupture is practically equal to the tensile strength, and nearly independent of the ratio of the diameter of the tube to the thickness, d/t ratio, while for the chrome-molybdenum tubing tested the modulus of rupture averages 20 per cent higher than the tensile strength and is markedly dependent on the d/t ratio. The cause of this difference has not been investigated, but it is thought to be related to the difference in shape of the stress-strain curves of the two materials.

Structures for airships.—Tests on airship girders and their chord members have been continued, the greater portion of the time being spent on box girders similar in general design to those used in some parts of the *Los Angeles*. In these, lattices are not used, but the chord members and webs of one side of the girder are stamped in one piece and four (or sometimes three) of these riveted together to from the girder. These have shown about the same chord-member stresses as the tubular type of lattice girder, giving no evidence of twisting failure of the chord members. Their strength-weight ratio is higher, however, because the material in the lightened webs is relatively lighter than the lattices in the latticed tubular girders.

The studies designed to relate the occurrence of twisting instability in chord members to the three (or possibly four) constants of the chord member and the rigidity of the lattice or web support have so far not resulted in any quantitative relationships being found, although the general character of the effects seems clear.

Electrically welded steel tubing.—The possibility of producing tubing more cheaply and with thinner and more uniform walls by automatic welding of flat strip which has been rolled up into a tube than is at present possible with seamless tubing has led to a comprehensive investigation of electrically welded steel tubing. So far the tests have included tension, torsion, bursting, crushing, and flattening tests on 100 different low-carbon-steel tubes ranging in outside diameter from five-eighths inch to 3 inches and in thickness from 0.028 to 0.095 inch.

In these tests the welded tubes have compared favorably with seamless tubing of the same composition. It is planned to extend the tests to axial compression and combined compression and bending with tubes of higher carbon content so as to furnish a direct comparison with the duralumin and chrome-molybdenum tubing now being tested.

Welded joints in tubing.—The Department of Commerce in administering the inspection and airworthiness provisions of the air commerce act of 1926, found great diversity in commercial practice in the design of joints and fittings, and no comprehensive test data by which to compare their relative value. On the advice of the structures subcommittee the design of welded joints in tubing was selected as the first problem to be investigated.

In consultation with airplane manufacturers, the Army Air Corps, the Bureau of Aeronautics of the Navy, and the American Bureau of Welding a thorough preliminary study of joint types, welding procedure, and test methods has been made.

Test fixtures have been constructed and tried out on the different types of welded joints. The program of tests includes about 135 types of 2 and 3 piece joints in seamless chrome-molybdenum and carbon-steel tubing. The welding will be done under procedure specifications prepared in cooperation with the American Bureau of Welding.

Technique of testing flat plates under normal pressure.—The data on which the design of flat plates under normal pressure is based are almost wholly taken from tests on relatively thick plates such as ship plating. Even for thick plating practically no tests have been made except on single panels with normally fixed (clamped) edges. The increasing use in aircraft of thin plates supported by ribbing is sufficiently important to make it desirable to have methods for convenient testing of varied designs under different conditions of edge constraint. A small testing apparatus has been built and methods are being developed for sealing against hydrostatic pressure under different types of edge constraints (fixed, supported, etc.) which permit of easy change of specimens.

Welding of corrosion-resisting steels.—The difficulties which have been encountered with corrosion of metallic aircraft structures has led to a search for measures to protect the usual materials and for materials which will resist the corrosion by virtue of their own constitution. Corrosion-resisting high-chromium steels have been introduced into the industry for many purposes and would appear to afford very satisfactory solutions for many of the difficulties encountered with corrosion if their adaptability for the processes and constructions used in the manufacture of aircraft were demonstrated. Since practically all fuselages made in this country are of steel tubing welded together, the use of corrosion-resisting steel for this purpose would be dependent upon the ability to produce satisfactory welds. Similarly, the use of corrosion-resisting steels in fittings depends upon the same ability to produce welds. At the instance of the committee a paper was prepared by Mr. W. B. Miller on welding high-chromium steels. This was issued by the National Advisory Committee for Aeronautics as Technical Note No. 290.

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PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are four series of publications, namely, Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars.

The Technical Reports present the results of fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 26 Technical Reports were submitted for publication.

Technical Notes present the results of small research investigations and the results of studies of specific detail problems which form parts of long investigations. The committee has issued during the past year, in mimeographed form, 31 Technical Notes.

Techincal Memorandums contain translations and reproductions of important aeronautical articles of a miscellaneous character. A total of 51 Technical Memorandums were issued during the past year.

Aircraft Circulars contain translations or reproductions of articles descriptive of new types of aircraft. During the past year 26 Aircraft Circulars were issued.

Summaries of the 26 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars follow:

SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report, Nos. 233 to 256; the thirteenth annual report, Nos. 257 to 282; and since the preparation of the thirteenth annual report for the year 1927 the committee has authorized the publication of the following Technical Reports, Nos. 283 to 308:

Report No. 283, entitled "A Preliminary Investigation of Supercharging an Air-Cooled Engine in Flight," by Marsden Ware and Oscar W. Schey, National Advisory Committee for Aeronautics.

This report presents the results of tests made in a preliminary investigation of the effects of supercharging an air-cooled engine under airplane flight conditions.

This investigation comprises the first of its kind that has been conducted and for which results have been published.

Service training airplanes were used in the investigation equipped with production types of Wright J engines. An N. A. C. A. Roots type supercharger was driven from the rear of the engine.

In addition to measuring those quantities that would enable the determination of the climb performance, measurements were made of the cylinder-head temperatures and the carburetor pressures and temperatures. The supercharging equipment was not removed from the airplane when making flights without supercharging, but a by-pass valve, which controlled the amount of supercharging by returning to the atmosphere the surplus air delivered by the supercharger, was left full open.

With the supercharger so geared that ground-level pressure could be maintained to 18,500 feet, it was found that the absolute ceiling was increased from 19,400 to 32,600 feet, that the time to climb to 16,000 feet was decreased from 32 to 16 minutes, and that this amount of supercharging apparently did not injure the engine.

Report No. 284, entitled "The Comparative Performance of Roots Type Aircraft Engine Superchargers as Affected by Change in Impeller Speed and Displacement," by Marsden Ware and Ernest E. Wilson, National Advisory Committee for Aeronautics.

This report presents the results of tests made on three sizes of Roots type aircraft engine superchargers. The impeller contours and diameters of these machines were the same, but the lengths were 11, 8¼, and 4 inches, giving displacements of 0.509, 0.382, and 0.185 cubic foot per impeller revolution. The information obtained serves as a basis for the examination of the individual effects of impeller speed and displacement on performance and of the comparative performance when speed and displacement are altered simultaneously to meet definite service requirements.

According to simple theory, when assuming no losses, the air weight handled and the power required for a given pressure difference are directly proportional to the speed and the displacement. These simple relations are altered considerably by the losses.

In estimating the effect of speed on performance it is of interest to note that—

(1) The difference between the actual power and the theoretical power was found to vary with the speed raised to the 2.5 power. The theoretical power was obtained by multiplying the pressure difference by the displacement and speed and dividing by the horsepower constant.

(2) The volumetric efficiency of the actual machine remains nearly constant over a large part of the interesting speed range, the decrease in volumetric efficiency at a speed of 6,000 r. p. m. being less than 2 per cent.

(3) The ratio of the discharge air temperature to the inlet temperature was found to depend on speed. This effect of speed is represented by the coefficient C in the relation

$$\frac{T_2}{T_1}=C\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}},$$

which has a value of 1 at zero r. p. m., increasing to 1.04 at 6,500 r. p. m.

With regard to the effect of displacement on performance, the following points are of interest:

(1) The power loss was found to increase with displacement.

(2) The maximum volumetric efficiency increased somewhat with increase in displacement.

(3) The relation between the inlet and discharge temperatures and pressures as represented by the exponent n in the above equation was found to increase from 1.36 to 1.53, with increase in impeller length from 4 to 11 inches.

When comparing the performance of different sizes of machines whose impeller speeds are so related that the same service requirements are met, it is found that the individual effects of speed and displacement are canceled to a large extent, and the only considerable difference is the difference in the power losses which decrease with increase in the displacement and the accompanying decrease in speed. This difference is small in relation to the net power of the engine supercharger unit, so that a supercharger with short impellers may be used in those applications where the space available is very limited without any considerable sacrifice in performance.

Report No. 285, entitled "A Study of Wing Flutter," by A. F. Zahm and R. M. Bear, construction department, Washington Navy Yard.

Part I describes vibration tests, in a wind tunnel, of simple airfoils and of the tail plane of an MO-1 airplane model; it also describes the air flow about this model. From these tests are drawn inferences as to the cause and cure of aerodynamic wing vibrations. Part II derives stability criteria for wing vibrations in pitch and roll, and gives design rules to obviate instability. Part III shows how to design spars to flex equally under a given wing loading and thereby economically minimize the twisting in pitch that permits cumulative flutter.

Resonant flutter is not likely to ensue from turbulence of air flow alone past wings and tail planes in usual flying conditions. To be flutter proof a wing must be void of reversible autorotation and not have its centroid far aft of its pitching axis; i. e., axis of pitching motion. Danger of flutter is minimized by so proportioning the wing's torsional resisting moment to the air pitching moment at high-speed angles that the torsional flexure is always small.

Report No. 286, entitled "Aerodynamic Characteristics of Airfoils—V," by the National Advisory Committee for Aeronautics.

This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for designing purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent of the chord length, the latter also serving as the datum line. When two sets of ordinates are necessary, on account of taper in chord or ordinate, those for the maximum section (at center of span) are given on the individual characteristic sheets, while those for the tip (dotted) section are given in separate tables (p. 375). The shape of the section is also shown with reasonable accuracy to enable one to more clearly visualize the section under consideration, the outside of the heavy line representing the profile.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, as explained under abbreviations, with the size of model, wind velocity, and year of test.

Report No. 287, entitled "Theories of Flow Similitude," by A. F. Zahm, construction department, Washington Navy Yard.

The laws of comparison of dynamically similar fluid motions are derived by three different methods based on the same principle and yielding the same or equivalent formulas. In this report are outlined the three current methods of comparing dynamically similar motions, more especially of fluids, initiated respectively by Newton, Stokes (or Helmholtz), and Rayleigh. These three methods—viz, the integral, the differential, and the dimensional—are enough alike to be studied profitably together.

Report No. 288, entitled "Pressure Distribution Over a Rectangular Monoplane Wing Model Up to 90° Angle of Attack," by Montgomery Knight and Oscar Loeser, jr., National Advisory Committee for Aeronautics.

The pressure distribution tests herein described, covering angles of attack up to 90°, were made on a rectangular monoplane wing model in the atmospheric wind tunnel of the Langley Memorial Aeronautical Laboratory.

These tests indicate that a rectangular wing, by reason of its large tip loads, is uneconomical aerodynamically and structurally, has pronounced lateral instability above maximum lift, and is not adaptable to accurate calculation based on the classical wing theory.

Report No. 289, entitled "Forces on Elliptic Cylinder in Uniform Air Stream," by A. F. Zahm, R. H. Smith, and F. A. Louden, construction department, Washington Navy Yard.

This report presents the results of wind tunnel tests on four elliptic cylinders with various fineness ratios, conducted in the Navy Aerodynamic Laboratory, Washington. The object of the tests was to investigate the characteristics of sections suitable for streamline wire which normally has an elliptic section with a fineness ratio of 4; also to learn whether a reduction in fineness ratio would result in improvement; also to determine the pressure distribution on the model of fineness ratio 4.

Four elliptic cylinders with fineness ratios of 2.5, 3, 3.5, and 4 were made and then tested in the 8 by 8 foot tunnel—first, for cross-wind force, drag, and yawing moment at 30 miles an hour and various angles of yaw; next for drag at 0° pitch and 0° yaw and various wind speeds; then for end effect on the smallest and largest models; and lastly for pressure distribution over the surface of the largest model at 0° pitch and 0° yaw and various wind speeds. In all tests, the length of the model was transverse to the current. The results are given for standard air density, $\rho = 0.002378$ slug per cubic foot.

Report No. 290, entitled "Water-Pressure Distribution on a Seaplane Float," by F. L. Thompson, National Advisory Committee for Aeronautics.

The investigation reported herein was conducted by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, Navy Department, for the purpose of determining the distribution and magnitude of water pressures likely to be experienced on seaplane hulls in service. It consisted of the development and construction of apparatus for recording water pressures lasting one one-hundredth second or longer and of flight tests to determine the water pressures on a UO-1 seaplane float under various conditions of taxiing, taking off, and landing.

The apparatus developed was found to operate with satisfactory accuracy and is suitable for flight tests on other seaplanes.

The tests on the UO-1 showed that maximum pressures of about 6.5 pounds per square inch occur at the step for the full width of the float bottom. Proceeding forward from the step the maximum pressures decrease in magnitude uniformly toward the bow, and the region of highest pressures narrows toward the keel. Immediately abaft the step the maximum pressures are very small, but increase in magnitude toward the stern and there once reached a value of about 5 pounds per square inch.

Report No. 291, entitled "Drag of C-Class Airship Hulls of Various Fineness Ratios," by A. F. Zahm, R. H. Smith, and F. A. Louden, construction department, Washington Navy Yard.

This report presents the results of wind-tunnel tests on eight C-class airship hulls with various fineness ratios, conducted in the Navy Aerodynamic Laboratory, Washington. The purpose of the tests was to determine the variation of resistance with fineness ratio, and also to find the pressure and friction elements of the total drag for the model having the least shape coefficient.

Seven C-class airship hulls with fineness ratios of 1, 1.5, 2, 3, 6, 8, and 10 were made and verified. These models and also the previously constructed original C-class hull, whose fineness ratio is 4.62, were then tested in the 8 by 8 foot tunnel for drag at 0° pitch and yaw, at various wind speeds. The original hull, which was found to have the least shape coefficient, was then tested for pressure distribution over the surface at various wind speeds.

Report No. 292, entitled "Characteristics of Five Propellers in Flight," by J. W. Crowley, jr., and R. E. Mixson, National Advisory Committee for Aeronautics.

This investigation was made for the purpose of determining the characteristics of five full-scale propellers in flight. The equipment consisted of five propellers in conjunction with a VE-7 airplane and a Wright E-2 engine. The propellers were of the same diameter and aspect ratio. Four of them differed uniformly in thickness and pitch and the fifth propeller was identical with one of the other four with the exception of a change of the airfoil section. The propeller efficiencies measured in flight are found to be consistently lower than those obtained in model tests. It is probable that this is mainly a result of the higher tip speeds used in the full-scale tests. The results show also that because of differences in propeller deflections it is difficult to obtain accurate comparisons of propeller characteristics. From this it is concluded that for accurate comparisons it is necessary to know the propeller pitch angles under actual operating conditions.

Report No. 293, entitled "Two Practical Methods for the Calculation of the Horizontal Tail Area Necessary for a Statically Stable Airplane," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.

This report is concerned with the problem of calculation of the horizontal tail area necessary to give a statically stable airplane. Two entirely different methods are developed, and reduced to simple formulas easily applied to any design combination. Detailed instructions are given for use of the formulas, and all calculations are illustrated by examples. The relative importance of the factors influencing stability is also shown.

Report No. 294, entitled "The Measurement of Maximum Cylinder Pressures," by Chester W. Hicks, National Advisory Committee for Aeronautics.

The work presented in this report was undertaken to determine a suitable method for measuring the maximum pressures occurring in aircraft engine cylinders. The study and development of instruments for the measurement of maximum cylinder pressures has been conducted in connection with carburetor and oil-engine investigations on a single cylinder aircraft-type engine. Five maximum cylinder-pressure devices have been designed, constructed, and tested, in addition to the testing of three commercial indicators.

Values of maximum cylinder pressures are given as obtained with various indicators for the same pressures and for various kinds and values of maximum cylinder pressures, produced chiefly by variation of the injection advance angle in a high-speed oil engine. It is the high pressure of short duration that is most difficult to measure, because the time of its duration is so short that little work can be done to operate an indicator.

The investigations conducted thus far indicate that the greatest accuracy in determining maximum cylinder pressures can be obtained with an electric, balanced-pressure diaphragm or disk-type indicator so constructed as to have a diaphragm or disk of relatively large area and minimum seat width and mass.

Report No. 295, entitled "The Variation in Engine Power with Altitude Determined from Measurements in Flight with a Hub Dynamometer," by W. D. Gove, National Advisory Committeee for Aeronautics.

The rate of change in power of aircraft engines with altitude has been the subject of considerable discussion. Only a small amount of data from direct measurements of the power delivered by airplane engines during flight, however, have been published. This report presents the results of direct measurements of the power delivered by a Liberty 12 airplane engine taken with a hub dynamometer at standard altitudes from zero to 13,000 feet. Six flights were made with the engine installed in a modified DH-4 airplane. The tests were conducted at the Langley Memorial Aeronautical Laboratory.

The experimental relation of brake horsepower to altitude is compared with two theoretical relations and with the experimental results, for a second Liberty 12 engine, given in N. A. C. A. Technical Report No. 252. The rate of change in power with altitude of a third Liberty engine, measured with a calibrated propeller, is also given for comparison.

The data presented substantiate the theoretical relation of brake horsepower to altitude based on the correction of ground level indicated horsepower for changes in atmospheric temperature and pressure with the subsequent deduction of friction horsepower corrected by altitude. The equation for this relation is

$$B.HP_a = B.HP^0\left[\left(\frac{P_a}{P_0}\right)\left(\frac{T_0}{T_a}\right)^{1/2}\left(1+\frac{\lambda-\lambda n}{n}\right)-\left(\frac{\lambda-\lambda n}{n}\right)\right]$$

where P is the absolute atmospheric pressure, T is the absolute temperature, n is the mechanical efficiency of the engine at sea level, and λ is the ratio of mechanical friction to friction horsepower at sea level. The subscripts $_0$ and $_a$ denote sea level and altitude conditions, respectively.

Report No. 296, entitled "Pressure Distribution Tests on PW-9 Wing Models from $-18°$ through 90° Angle of Attack," by Oscar E. Loeser, jr., National Advisory Committee for Aeronautics.

At the request of the Army Air Corps, an investigation of the pressure distribution over PW-9 wing models was conducted in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics. The primary purpose of these tests was to obtain wind-tunnel data on the load distribution on this cellule to be correlated with similar information obtained in flight tests, both to be used for design purposes. Because of the importance of the conditions beyond the stall as affecting control and stability, this investigation was extended th ough 90° angle of attack. The results for the range of normal flight have been given in N. A. C. A. Technical Report No. 271. The present paper presents the same results in a different form and includes, in addition, those over the greater range of angle of attack, $-18°$ through 90°.

The results show that—

At angles of attack above maximum lift, the biplane upper wing pressures are decreased by the shielding action of the lower wing.

The burble of the biplane lower wing, with respect to the angle of attack, is delayed, due to the influence of the upper wing.

The center of pressure of the biplane upper wing (semispan) is, in general, displaced forward and outward with reference to that of the wing as a monoplane, while for the lower wing there is but slight difference for both conditions.

The overhanging portion of the upper wing is little affected by the presence of the lower wing.

Report No. 297, entitled "The Reduction of Observed Airplane Performance to Standard Conditions," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.

This report shows how the actual performance of an airplane varies with air temperature when the pressure is held constant. This leads to comparatively simple methods of reducing observed data to standard conditions. The new methods which may be considered exact for all practical purposes, have been used by the Navy Department for about a year, with very satisfactory results.

The report also contains a brief historical review of the important papers which have been published on the subject of performance reduction, and traces the development of the standard atmosphere.

Report No. 298, entitled "Effect of Chord and Span of Ailerons on Rolling and Yawing Moments in Level Flight," by R. H. Heald and D. H. Strother, Bureau of Standards.

This report presents the results of an investigation of the rolling and yawing moments due to ailerons of various chords and spans on two airfoils having the Clark Y and U. S. A. 27 wing sections. Some attention is devoted to a study of the effect of scale on rolling and yawing moments and to the effect of slightly rounding the wing tips.

The results apply to level flight with the wing chord set at an angle of attack of $+4°$ and to conditions of zero pitch, zero yaw, and zero roll of the airplane. It is planned later to extend the investigation to other attitudes for monoplane and biplane combinations.

The work was conducted in the 10-foot wind tunnel of the Bureau of Standards on models of 60-inch span and 10-inch chord.

Report No. 299, entitled "Investigation of Damping Liquids for Aircraft Instruments," by G. H. Keulegan, Bureau of Standards.

This report covers the results of an investigation carried on at the Bureau of Standards under a research authorization from, and with the financial assistance of, the National Advisory Committee for Aeronautics.

The choice of a damping liquid for aircraft instruments is difficult owing to the range of temperature at which aircraft operate. Temperature changes affect the viscosity tremendously. The investigation was undertaken with the object of finding liquids of various viscosities otherwise suitable which had a minimum change in viscosity with temperature. The new data relate largely to solutions.

The effect of temperature on the kinematic viscosity of the following liquids and solutions was determined in the temperature interval $-18°$ to $+30°$ C.

(1) Solutions of animal and vegetable oils in xylene. These were poppy-seed oil, two samples of neat's-foot oil, castor oil, and linseed oil.

(2) Solutions of mineral oil in xylene. These were Squibb's petrolatum of naphthene base and transformer oil.

(3) Glycerine solutions in ethyl alcohol and in mixture of 50–50 ethyl alcohol and water.

(4) Mixtures of normal butyl alcohol with methyl alcohol.

(5) Individual liquids, kerosene, mineral spirits, xylene, recoil oil.

The apparatus consisted of four capillary-tube viscometers, which were immersed in a liquid bath in order to secure temperature control. The method of calibration and the related experimental data are presented in detail.

The viscosity data for the liquids are given in curves in which $\log_{10} \frac{t_\theta}{t_{30}}$ is plotted against temperature, where t_{30} and t_θ are, respectively, the times of discharge through the viscometer at 30° C. and $\theta°$ C. Except for a correction which is usually small, the following relation holds:

$$\log_{10} \frac{t_\theta}{t_{30}} = \log_{10} \frac{\nu_\theta}{\nu_{30}}$$

in which ν_{30} and ν_θ are, respectively, the kinematic viscosities at 30° C. and $\theta°$ C. The density at 30° C. the coefficient of cubical thermal expansion for each solution, and ν_{30} are given, together with other data, so that the absolute viscosity may be computed. The accuracy is within 1 per cent.

Report No. 300, entitled "The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics," by Fred E. Weick and Donald H. Wood, National Advisory Committee for Aeronautics.

This report describes in detail the new propeller research tunnel at Langley Field, Va. This tunnel has an open jet air stream 20 feet in dimeter in which velocities up to 110 miles per hour are obtained. Although the tunnel was built primarily to make possible accurate full-scale tests on aircraft propellers, it may also be used for making aerodynamic tests on full-size fuselages, landing gears, tail surfaces, and other aircraft parts, and on model wings of large size.

Report No. 301, entitled "Full Scale Tests of Wood Propellers on a VE–7 Airplane in the Propeller Research Tunnel," by Fred E. Weick, National Advisory Committee for Aeronautics.

The investigation described in this report was made primarily to afford a comparison between propeller tests in the new Propeller Research Tunnel and flight tests and small model tests on propellers. Three wood propellers which had been previously tested in flight on a VE–7 airplane, and of which models had also been tested in a wind tunnel, were tested again on a VE–7 airplane in the Propeller Research Tunnel. The results of these tests are in fair agreement with those of the flight and model tests.

Tests were also made with the tail surfaces removed, and with both the wings and tail surfaces removed. It was found that the effect of the tail surfaces on the propeller characteristics was negligible, but that the wings reduced the maximum propulsive efficiency about 5 per cent.

Report No. 302, entitled "Full Scale Tests on a Thin Metal Propeller at Various Tip Speeds," by Fred E. Weick, National Advisory Committee for Aeronautics.

This report describes an investigation made in order to determine the effect of tip speed on the characteristics of a thin-bladed metal propeller. The propeller was mounted on a VE–7 airplane with a 180-horsepower E–2 engine and tested in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. It was found that the effect of tip speed on the propulsive efficiency was negligible within the range of the tests, which was from 600 to 1,000 feet per second (about 0.5 to 0.9 the velocity of sound in air).

Report No. 303, entitled "An Investigation of the Use of Discharge Valves and an Intake Control for Improving the Performance of N. A. C. A. Roots Type Superchargers," by Oscar W. Schey and Ernest E. Wilson, National Advisory Committee for Aeronautics.

This report presents the results of an analytical investigation on the practicability of using mechanically operated discharge valves in conjunction with a manually operated intake control for improving the performance of N. A. C. A. Roots type superchargers. The investigation was conducted by the staff of the National Advisory Committee for Aeronautics at Langley Field, Va.

These valves, which may be either of the oscillating or rotating type, are placed in the discharge opening of the supercharger and are so shaped and synchronized with the supercharger impellers that they do not open until the air has been compressed to the delivery pressure. The intake control limits the quantity of air compressed to engine requirements by permitting the excess air to escape from the compression chamber before compression begins.

The percentage power saving and the actual horsepower saved were computed for altitudes from 0 to 20,000 feet. These computations are based on the pressure-volume cards for the conventional and the modified Roots type superchargers and on the results of laboratory tests of the conventional type.

The use of discharge valves shows a power saving of approximately 26 per cent at a critical altitude of 20,000 feet. In addition, these valves reduce the amplitude of the discharge pulsations and increase the volumetric efficiency. With slow-speed Roots blowers operating at high-pressure differences even better results would be expected. For aircraft engine superchargers operating at high speeds these discharge valves increase the performance as above, but have the disadvantages of increasing the weight and of adding a high-speed mechanism to a simple machine.

Report No. 304, entitled "An Investigation of the Aerodynamic Characteristics of an Airplane Equipped with Several Different Sets of Wings," by J. W. Crowley, jr., and M. W. Green, National Advisory Committee for Aeronautics.

This investigation was conducted by the National Advisory Committee for Aeronautics at Langley Field, Va., at the request of the Army Air Corps, for the purpose of comparing the full scale lift and drag characteristics of an airplane equipped with several sets of wings of commonly used airfoil sections. A Sperry Messenger airplane with wings of R. A. F.–15, U. S. A.–5, U. S. A.–27, and Göttingen 387 airfoil sections was used and the lift and drag characteristics of the airplane with each set of wings were determined by means of glide tests.

The results are presented in tabular and curve form.

Report No. 305, entitled "The Gaseous Explosive Reaction—A Study of the Kinetics of Composite Fuels," by F. W. Stevens, Bureau of Standards.

This report deals with the results of a series of studies of the kinetics of gaseous explosive reactions where the fuel under observation, instead of being a simple gas, is a known mixture of simple gases. In the practical application of the gaseous explosive reaction as a source of power in the gas engine, the fuels employed are composite, with characteristics that are apt to be due to the characteristics of their components and hence may be somewhat complex. The simplest problem that could be proposed in an investigation either of the thermodynamics or kinetics of the gaseous explosive reaction of a composite fuel would seem to be a separate study of the reaction characteristics of each component of the fuel and then a study of the reaction characteristics of the various known mixtures of those components forming composite fusel more and more complex. This is the order followed in the simple studies described.

Report No. 306, entitled "Full Scale Wind Tunnel Tests of a Series of Metal Propellers on a VE–7 Airplane," by Fred E. Weick, National Advisory Committee for Aeronautics.

An adjustable blade metal propeller was tested at five different angle settings, forming a series varying in pitch. The propeller was mounted on a VE–7 airplane in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. The efficiencies were found to be from 4 to 7 per cent higher than those of standard wood propellers operating under the same conditions. The results are given in convenient form for use in selecting propellers for aircraft.

Report No. 307, entitled "The Pressure Distribution Over the Horizontal and Vertical Tail Surfaces of the F6C–4 Pursuit Airplane in Violent Maneuvers," by R. V. Rhode, National Advisory Committee for Aeronautics.

This investigation of the pressure distribution on the tail surfaces of a pursuit airplane in violent maneuvers was conducted by the National Advisory Committee for Aeronautics at the request of the Navy Bureau of Aeronautics for the purpose of determining the maximum loads likely to be encountered on these surfaces in flight. The information is a part of that needed for a revision of existing loading specifications to bring these into closer agreement with actual flight conditions. A standard F6C–4 airplane was used and the pressure distribution over the right horizontal and complete vertical tail surfaces was recorded throughout violent maneuvers. The results show that the existing loading specifications do not conform satisfactorily to the loadings existent in critical conditions, and in some cases were exceeded by the loads obtained.

An acceleration of 10.5 *g* was recorded in one maneuver in which the pilot suffered severely. It is therefore indicated that the limits of the physical resistance of the pilot to violent maneuvers are being approached.

Navy specifications for the structural design of tail surfaces are included as an appendix.

Report No. 308, entitled "Aircraft Accidents: Method of Analysis," prepared by special committee on the nomenclature, subdivision, and classification of aircraft accidents, National Advisory Committee for Aeronautics.

This report on a method of analysis of aircraft accidents has been prepared by a special committee on the nomenclature, subdivision, and classification of aircraft accidents organized by the National Advisory Committee for Aeronautics in response to a request dated February 18, 1928, from the air coordination committee consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce. The work was undertaken in recognition of the difficulty of drawing correct conclusions from efforts to analyze and compare reports of aircraft accidents prepared by different organizations using different classifications and definitions. The air coordination committee's request was made "in order that practices used may henceforth conform to a standard and be universally comparable." The purpose of the special committee therefore was to prepare a basis for the classification and comparison of aircraft accidents, both civil and military.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

267. Pressure Distribution on Wing Ribs of the VE–7 and TS Airplanes in Flight. By R. V. Rhode. Part I: Level Flight.
268. Mass Distribution and Performance of Free Flight Models. By Max Scherberg and R. V. Rhode.
269. The Distribution of Loads Between the Wings of a Biplane Having Decalage. By Richard M. Mock.
270. The Characteristics of the N. A. C. A. 97, Clark Y, and N. A. C. A.–M6 Airfoils with Particular Reference to the Angle of Attack. By George J. Higgins.

No.
271. Full Scale Drag Tests on Various Parts of Sperry Messenger Airplane. By Fred E. Weick.
272. Special Propeller Protractor. By. A. L. Heim.
273. The Effect on Performance of a Cutaway Center Section. By Thomas Carroll.
274. The Effect of the Sperry Messenger Fuselage on the Air Flow at the Propeller Plane. By Fred E. Weick.
275. Determination of Propeller Deflection by Means of Static Load Tests on Models. By Fred E. Weick.
276. Helium Tables. By Lieut. Commander Clinton H. Havill, U. S. N.
277. Pressure Distribution on Wing Ribs of the VE-7 and TS Airplanes in Flight. Part II: Pull-Ups. By R. V. Rhode.
278. An Automatic Speed Control for Wind Tunnels. By A. F. Zahm.
279. Resistance of Streamline Wires. By George L. DeFoe.
280. Drag of Exposed Fittings and Surface Irregularities on Airplane Fuselages. By Donald H. Wood.
281. A Comparison of Propeller and Centrifugal Fans for Circulating the Air in a Wind Tunnel. By Fred E. Weick.
282. Corrosion Embrittlement of Duralumin. I. Practical Aspects of the Problem. By Henry S. Rawdon.
283. Corrosion Embrittlement of Duralumin. II. Accelerated Corrosion Tests and the Behavior of High-Strength Aluminum Alloys of Different Compositions. By Henry S. Rawdon.
284. Corrosion Embrittlement of Duralumin. III. Effect of the Previous Treatment of Sheet Material on the Susceptibility to this Type of Corrosion. By Henry S. Rawdon.
285. Corrosion Embrittlement of Duralumin. IV. The Use of Protective Coatings. By Henry S. Rawdon.
286. Preliminary Investigation on Boundary Layer Control by Means of Suction and Pressure with the U. S. A. 27 Airfoil. By E. G. Reid and M. J. Bamber.
287. A Dangerous Seaplane Landing Condition. By Thomas Carroll.
288. The Reaction on a Float Bottom When Making Contact with Water at High Speeds. By H. C. Richardson.
289. Preliminary Biplane Tests in the Variable Density Wind Tunnel. By James M. Shoemaker.
290. Welding High Chromium Steels. By W. B. Miller.
291. Gluing Practice at Aircraft Manufacturing Plants and Repair Stations. By T. R. Truax.
292. The Drag of a J-5 Radial Air-Cooled Engine. By Fred E. Weick.
293. The Formation of Ice Upon Exposed Parts of an Airplane in Flight. By Thomas Carroll and William H. McAvoy.
294. Wind Tunnel Force Tests in Wing Systems Through Large Angles of Attack. By Carl J. Wenzinger and Thomas A. Harris.
295. The Effect of Tip Shields on a Horizontal Tail Surface. By Paul V. Dronin, Earl I. Ramsden, and George J. Higgins.
297. Preliminary Report on the Flar-Top Lift Curve as a Factor in Control at Low Speed. By Montgomery Knight and Millard J. Bamber.
298. The Determination of Several Spray Characteristics of a High-Speed Oil Engine Injection System with an Oscilloscope. By Chester W. Hicks and Charles S. Moore.

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No.
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433. Some German Gliders of 1920-1923. By Alfred Gymnich. Translation from "Der Gleit- und Segelflugzeugbau" (ch. 3). Published by Richard Carl Schmidt & Co., Berlin, 1925.
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No.

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437. Experiments on Airfoils with Aileron and Slot. By A. Betz. Translation from Report III, "Ergebnisse der Aerodynamischen Versuchsanstalt zu Gottingen" (Aerodynamic Institute).

438. Safety in Airplane Flight. By H. Brunat. Communication by H. Brunat, of the "Service de la Navigation Aérienne," to the "Société Française de Navigation Aérienne," November 10, 1927.

439. Structural Details of German Gliders. By Alfred Gymnich. Translation from "Der Gleit- und Segelflugzeugbau" (ch. 4, secs. 6–9), 1925.

440. Metal Aircraft Construction at Vickers. Some Interesting New Forms Developed. From Flight, September 15, 1927.

441. Increasing Lift by Releasing Compressed Air on Suction Side of Airfoil. By F. Seewald. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," August 16, 1927.

442. "Gloster" High-Lift Biplane Wings. By H. E. Preston. From The Gloster, Volume II, No. 5, January-February, 1927.

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448. Mechanical Properties of Some Materials Used in Airplane Construction. By E. B. Wolff and L. J. G. Van Ewijk. Translation from Report M 219 of the "Rijks-Studiedienst voor de Luchtvaart," reprinted from "De Ingenieur," August 7, 1926.

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450. Parachutes for Aircraft. By Waldemar Müller. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," October 28, 1927.

451. Aviation Fuels (with Special Reference to "White Spirit"). By P. Dumanois. Translation from "La Technique Aeronautique," April 15, 1927.

452. Motion of Fluids with Very Little Viscosity. By L. Prandtl. Translation from "Vier Abhandlungen zur Hydrodynamik und Aerodynamik," Göttingen, 1927.

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454. The 1926 German Seaplane Contest. Part I: Lessons Taught. By F. Seewald. Part II: Method of Rating. By H. Blenk and F. Liebers. Translation from the 1927 Yearbook of the "Deutsche Versuchsanstalt für Luftfahrt."

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No.

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465. Discussion of Problems Relating to the Safety of Aviation. By J. Sabatier. Part II. Translation from "Bulletin Technique" No. 42, of the "Service Technique et Industriel de l'Aeronautique," June 18, 1927.

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473. (II) The Problem of Noise in Civil Aircraft and the Possibilities of Its Elimination. By W. S. Tucker. From Journal of the Royal Aeronautical Society, March, 1928, volume 32, No. 207.

474. Windmills in the Light of Modern Research. By A. Betz. Translation from "Die Naturwissenschaften," November 18, 1927, volume 15, No. 46.

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No.

477. Contribution to the Design and Calculation of Fuel Cams and Fuel Valves for Diesel Engines. By Jatindra Nath Basu. Translation from "Der Motorwagen," May 10 and July 31, 1927.
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No.

57. The De Haviland *Tiger Moth*—A Low-Wing Monoplane. From Flight, September 22, 1927.
58. The Fairchild *All-Purpose* Cabin Monoplane. From a circular issued by the Fairchild Airplane Manufacturing Corporation.
59. The Focke-Wulf F. 19 *Ente* Tail-First Airplane. From Flight, September 29, 1927.
60. Stinson Commercial Airplane, type SM-1—A Semicantilever Monoplane. Prepared by the Stinson Aircraft Corporation.
61. Lockheed *Vega* Airplane—A Commercial Cabin Monoplane. Prepared by the Lockheed Aircraft Co.
62. The Pitcairn *Mailwing* PA-5—A Single-Seat Commercial Biplane. Prepared by Pitcairn Aviation (Inc.).
63. *Avimeta*—Three-Engine Commercial Monoplane, type A. V. M. 132. From a circular issued by the Avimeta Co.
64. The Heinkel Commercial Airplane *H. D. 40* From a circular issued by the Ernst Heinkel Airplane Co.
65. The De Haviland 61 *Canberra* (British)—A Six to Eight Passenger Airplane. From Flight, December 29, 1927.
66. Focke-Wulf A. 17 Commercial Airplane *Moewe* (German). From a circular issued by the Focke-Wulf Airplane Construction Co.
67. Supermarine *S-5* Seaplane (British)—Winner of the 1927 Schneider Cup Race. From Flight, February 16, 1928.
68. The Short *Calcutta*—First British All-Metal Commercial Seaplane. From Flight, February 23, 1928.
69. The *Gloster IV* Seaplane (British). From Flight, March 1, 1928.
70. The Avro *Avian III* Airplane (British). From Flight, March 8, 1928.
71. The Boulton and Paul *Sidestrand I* Bomber Airplane (British). From Flight, March 29, 1928.
72. The Parnall *Imp*—A New British Light Airplane. From Flight, April 12, 1928.
73. The Fokker *Universal* Commercial Airplane. From a circular issued by the Atlantic Aircraft Corporation.
74. The Bleriot *Spad 91* Airplane—Pursuit Single-Seater "Jockey" type. Translation from Les Ailes, April 19, 1928.
75. Morane-Saulnier 121 Single-Seat Pursuit Airplane (French). By J. Serryer. Translation from Les Ailes, October 20, 1927.
76. The Fokker *Trimotor F VII* Commercial Transport Monoplane. From a circular issued by the Atlantic Aircraft Corporation.
77. René Couzinet Monoplane (French). By J. Serryer. Translation from Les Ailes, March 29, 1928.
78. Savoia Marchetti *S 64* Airplane. By Maurice Victor. Translation from Les Ailes, June 14, 1928.

No.

79. The Sikorsky Twin-Engined Amphibian, type S–38, Model 1928. Prepared by Sikorsky Manufacturing Corporation.
80. C. A. M. S. *54 G. R.* Transatlantic Seaplane (French). Prepared by Paris Office, N. A. C. A.
81. Westland *Wapiti* (British). Prepared by the Westland Aircraft Works, England.
82. The Armstrong Whitworth *Starling* (British)—Single-Seat Fighter. From Flight, August 2, 1928.

BIBLIOGRAPHY OF AERONAUTICS

During the past year the committee issued a bibliography of aeronautics for the year 1925. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, 1922, 1923, and 1924. A bibliography for the year 1926 is now in the hands of the printer, and should be ready for distribution during the coming year. A bibliography is now being published annually by the committee.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

PART V

THE PRESENT STATE OF AERONAUTICAL DEVELOPMENT

PROGRESS IN TECHNICAL DEVELOPMENT

AERODYNAMICS

As in past years a majority of the aerodynamic problems investigated have been closely related either to particular design requirements or to the study of unusual phenomena. Their study has been made necessary by the immediate technical requirements of air commerce and the military and naval services. These problems usually demand prompt attention, and it has always been the policy of the committee to undertake as much of this type of work as practicable without unbalancing the research programs. Fundamental research along lines having no immediate prospect of practical use is as a rule limited to problems of general interest, but whenever possible the test programs are so laid out as to have a bearing on some fundamental problem.

WIND TUNNELS—*Additional equipment.*—There have been several additions to the wind-tunnel equipment at the Langley Memorial Aeronautical Laboratory and others are planned. A small wind tunnel having a 6-inch jet has been constructed and fitted with refrigerating apparatus to enable the study of ice formation. A small water tunnel has also been constructed for use in the study of scale effect. A high-speed tunnel has been added to the equipment of the variable-density tunnel. This new tunnel gives an air stream about 1 foot in diameter with a velocity in the neighborhood of that of sound. Steps are also being taken to replace the present 5-foot atmospheric wind tunnel by two new tunnels. One will be a somewhat larger closed-circuit open-throat tunnel and the other a smaller tunnel having a vertical air flow in the testing section. This latter tunnel is for use in the study of spinning. The additional equipment will be of great value in expediting important tests now on the program.

Aerodynamic safety.—Considerable work has been done in the atmospheric wind tunnel in connection with the problems of safety. Attention has been focused on the possibility of the development of an airfoil having a flat-top lift curve as a means of preventing accidental stalls in landing or taking off. This work is being continued in an attempt to improve the aerodynamic characteristics of the N. A. C. A. 84 airfoil section and to develop a suitable section for full-flight testing. This research is considered highly important and it will be made in conjunction with the investigation of lateral control and autorotation.

Autorotation.—The research on autorotation has been continued and during the past year force tests have been made through a large range of angles of attack for a systematic series of monoplane and biplane combinations. This research is being supplemented by pressure-distribution tests now under way, upon completion of which it is proposed to make a series of autorotational torque tests on a specially designed dynamometer. The primary object of these investigations is to supply information for the development of nonspinning wings or wing systems. Several reports have already been issued.

Ice formation.—This problem, as apart of the general safety program, has been studied in the laboratory with a special 6-inch wind tunnel equipped with refrigerating apparatus. Preliminary tests have been very satisfactory in that ice formations have been obtained on model air foils and struts similar to those observed on airplanes in flight. The investigation will be extended to determine practical means for the prevention or the avoidance of ice formations.

Slots and flaps.—Several types of trailing-edge flaps have been tested and this work is to be extended to cover the effects of slots, singly and in combination with various flaps. This investigation is made as a part of the research on control and stability at low speeds.

Variable-density wind tunnel.—Following the fire in 1927, which completely destroyed the interior fittings, this tunnel has been rebuilt and improved. It has been converted to an open-throat type and preliminary tests indicate a marked improvement in the energy ratio, with a better velocity distribution. The new balance is expected to be installed and the tunnel again in full operation at an early date.

FREE FLIGHT TESTS—*Flight-path determination.*—Two independent methods have been used for measuring the flight path of airplanes in a very important research on this subject. The integrated indications of special recording instruments developed for this purpose are checked by simultaneous ground records made with a camera obscura. The test runs are controlled from the ground by radiotelephone communication with the pilot. The results of this investigation will supply information regarding the comparative maneuverability of various airplanes, the loadings encountered, and similar information of value in the design and operation of airplanes. Flight tests have been completed on one airplane and have been partially completed on a second differing from the first in the engine installation only.

Ice formation.—A number of flight tests have been made to study the conditions under which ice forms on the wings, struts, wires, etc., of an airplane. In these flights records are made of cloud formations, altitude, temperature, etc. Various methods of preventing or avoiding ice formation will be studied and the data obtained will be correlated with that from the wind-tunnel tests.

Landing-gear loads.—Dropping tests, followed by flight tests, are under way on airplane landing gear equipped with several types of oleo and rubber shock absorbers in order to obtain quantitative values of the energy absorbed and the accelerations resulting from different kinds of landings. This investigation will supply data for the more accurate design of landing gears fitted with the various types of shock absorbers.

Loading on float bottoms.—The research on water pressure distribution on float bottoms has been continued on a twin-float seaplane with very satisfactory results. The maximum pressures measured were considerably less than those given in the design specifications. It would appear that by designing for the lighter loads the weight of airplane floats could be reduced.

Pressure distribution.—Pressure-distribution tests have been completed on the entire control and supporting surfaces of a modern pursuit airplane and the investigation is being extended to cover the pressure distribution on the fuselage. Pressure-distribution tests on the tail surfaces of another pursuit-type airplane have also been completed and the results will soon be published. These investigations indicate that the present specifications for the loads on control surfaces should be revised and recommendations to this effect have been made to the Army and the Navy. The present pressure-distribution program includes cargo and observation types. The information obtained from this work is invaluable to the designer.

Spinning.—In connection with the study of recovery from spins the moments of inertia of all available airplanes have been measured. These data are now being analyzed with reference to normal and abnormal spinning characteristics. This information is expected to supplement the wind-tunnel autorotation study in supplying the designer with fairly definite restrictions on weight distribution.

Take-off and landing runs.—The investigation of take-off runs has been continued and tests have been made on one airplane with three loads and three different propellers. The test data now available are being analyzed in order to establish if practicable a simple empirical formula for take-off runs. Landing runs have also been measured with and without brakes under various conditions. The information so far obtained is of considerable interest and value to commercial pilots operating from small fields.

PROPELLER RESEARCH TUNNEL.—During the past year this tunnel has made a number of tests on propellers, propeller interference, full-scale drag, and cowling and cooling of air-cooled engines. The information obtained is of the highest value.

Cowling and cooling of air-cooled engines.—This investigation is one of the most important studies yet made by the committee and the results have been highly gratifying. The full-scale

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information now made available for the first time is of fundamental importance in design. The data include full-scale drag measurements on radial air-cooled engines with installations ranging from no cowling to complete cowling, the cooling characteristics and the propulsive characteristics being measured for each installation. Incidental to the main investigation a number of important tests were also made such as the drag of various types of exhaust stacks and collector rings and the drag of various types of bodies and fairings. Obviously, this information is of the greatest value to the designer of commercial and military airplanes.

Effect of tip speed.—Tests have been made on a thin metal propeller mounted on a VE–7 fuselage, at tip speeds from 600 to 1,000 feet per second. Within this range the effect of tip speed on propulsive efficiency was negligible, but the investigation will be extended to include higher tip speeds and other blade shapes.

Miscellaneous drag measurements.—A number of very important full-scale drag measurements have been made during the propeller testing program. One of the most important of these was the drag analysis of the Sperry messenger airplane. A full-scale airplane was mounted on the balance, and the drag measured as successive parts were removed until there remained only the bare fuselage. The results were highly satisfactory and indicate the great possibilities of the propeller research tunnel. Another test of considerable interest was the determination of the effect of wing fillets on drag. Using one of the "cowling" investigation models, it was found that fillets of 6-inch and 12-inch radii between the lower wing surface and the fuselage reduced the drag 2 pounds and 5.1 pounds, respectively, at 100 miles per hour.

A special gear has been devised and used for the testing of mode s of wings up to 3-foot chord by 12-foot span, at a speed of 100 miles per hour. Full-scale tests were made with this equipment on four airfoils and a full-scale racing wing fitted with wing radiators.

Propeller interference.—Considerable information on this subject has now been accumulated. In the VE–7 tests, readings were obtained with the tail surfaces removed and then with wings and tail removed. The tail surfaces were found to have no appreciable effect on the propeller, but the wings reduced the propulsive efficiency and increased the power coefficient. In the cowling and cooling investigation, the data on propeller interference will form a considerable item. These tests are now nearing completion and the data will soon be available for design purposes.

VE–7 airplane with various propellers.—A full-scale VE–7 fuselage has been tested with two series of propellers, one wood and one metal. The wooden series had previously been tested in flight and in model form in a wind tunnel. The metal-propeller series was obtained from five blade-angle settings for a service propeller. The data so obtained are very important in propeller design and further work is to be done.

LIGHTER-THAN-AIR CRAFT.—A preliminary study of wind velocities and accelerations in bumpy air has been concluded with satisfactory results. Accelerations were found ranging from 121 feet per second, per second lasting ¼ second, to 2 feet per second, per second lasting 15¼ seconds, but the preliminary study was made for the purpose of trying out instruments and finding the magnitude of the accelerations to be expected. The next step is to determine the size or extent of the gusts, and it is planned to cover a large area with recording instruments for this purpose.

The results of the pressure-distribution, speed, and acceleration tests on the *Los Angeles* have been worked up and will soon be ready for publication.

FIELDS FOR FUTURE RESEARCH.—It has been pointed out in previous summaries that the greatest progress in aerodynamics may be expected along the line of refinement in design and increase in safety. The refinement will result from improved knowledge regarding air loads and load distribution, the phenomena which affect control and control effectiveness particularly at low speeds, full-scale wing characteristics, and methods of reducing drag or improving propulsive efficiencies. The increasing of safety is obviously very closely connected with the problems encountered in general design refinement. The present research programs are based on these considerations.

The immediate design needs are for more information on loads and load distributions in commercial types of airplanes and for additional data on mutual interference between propellers and structure, particularly in multi-engined installations. The questions regarding safety are considered to be by far the most important facing the committee and the aircraft industry. These questions relate chiefly to stability, control, and operation, rather than structural strength.

The propeller research wind tunnel has been of great value in the investigation of design problems that can not be studied in smaller wind tunnels or in free flight. The information so far obtained has indicated that the future development of aeronautics can be greatly accelerated by the provision of a wind tunnel large enough for testing full-scale airplanes up to, say, 35-foot span. The need for this equipment is so great that the design of such a tunnel has been started and tests on small-scale models are now being made.

AIRPLANE STRUCTURES

TREND OF DESIGN—*Standardization of types.*—No notable changes from the tendencies noted in last year's report have appeared. The monoplane appears firmly established for regular scheduled commercial service carrying passengers and express. These airplanes practically invariably have two or more engines. An increasing appreciation of the importance of reducing parasite resistance has led to improved performances from airplanes of this type. The monoplane is also beginning to appear in the smaller classes of airplanes where its better aerodynamic efficiency usually enables either a reduction in engine power for the same performance as the generally equivalent biplane, or a better performance for the same power.

The biplane, however, continues to hold a large place in production and is profiting by the appreciation of the necessity for reducing parasite resistance. By far the larger number of the airplanes sold for use by individual owners and pilots are of this type.

Inclosed or cabin-type bodies are being fitted in increasing numbers and in airplanes of all types and sizes. Apparently the old feeling that the pilot could not handle his craft properly unless he were in an open cockpit is rapidly fading. This also reflects the demand of the new owners of airplanes for increased comfort.

The influence of the production department on the designer of airplanes is beginning to be apparent. This is leading to the construction of airplanes which, without sacrifice of quality in design, materials, or performance, are less costly to produce than many earlier designs.

Monoplane bombers have not been as successful as was hoped, and bombers of this type are still strictly experimental.

The military biplanes for any particular service continue to grow more alike. Experience under service conditions quickly weeds out the airplanes having undesirable characteristics and shows that in order to obtain desirable ones the arrangement of parts must be along fairly restricted lines.

Number and location of engines.—As the engines available increase in power the tendency to use several engines in military aircraft is reduced. Most multi-engined military aircraft can not fly loaded with one engine out of commission. A single engine of the same total horsepower is usually lighter and the airplane has less structure in the wind to produce resistance.

In civil aircraft the effort is distinctly to enable flight to continue if one engine is out of commission. For such aircraft several engines offer a real increase in safety. However, the use of several engines continues to be uneconomic in the smaller types carrying either mail or only a few passengers.

The tendency to locate the engines well above the wing, which has been a conspicuous feature in large foreign monoplanes, has not yet appeared in American designs, where the lines of thrust of all propellers are usually approximately in the same plane which passes very close to the fore-and-aft center line of the body. The effect of overlapping propeller circles in producing vibration and reducing efficiencies has been appreciated, and in most of the recent designs of multi-engined airplanes the distance apart of the engines has been made sufficient to prevent overlap of propellers. Advantage is usually taken of the construction which is made necessary by the greater distance apart to fit the landing wheels directly under the outer engines, thus widening the track and reducing the structure in the wind.

Amphibian airplanes.—The amphibian type of airplane has grown in favor and several manufacturers now offer production models. Most of the earlier models were of the boat type and these still continue. Float type seaplanes incorporating amphibian gear were developed during the past year.

Landing gear.—Many airplane manufacturers are now prepared to supply their product as either landplane or seaplane. The arrangement is such that the change from one landing gear to the other is relatively easy and quick. Although not amphibian these interchangeable gears make the airplane much more adaptable for service in a variety of locations. By arranging for the fitting of skis also the same airplane can be used in a wide range of services.

Shock absorbers.—The old rubber-cord shock absorber is being fitted on few new airplanes. The general use of the hydraulic shock absorber with the resulting lighter landing gear loads, has led to the raising of the question whether the structure of the airplane might not be reduced accordingly.

Wheel tail skids.—These are being introduced in both large and small airplanes and are being applied to increasing numbers. They are, of course, invariably associated with wheel brakes on at least the main landing wheels.

Brakes.—The general application of brakes has reduced the amount of manhandling of airplanes on the field. With increased knowledge of how to use the brakes new methods of handling have appeared. Many pilots land and bring their airplanes to the line or point for discharge of passengers and cargo without assistance from ground crews. Frequently the pilot "drives" right into a hangar and in some cases maneuvers inside on his own power.

New types of brakes and combinations of brakes and wheels and brakes and shock absorbers with the wheels are being tried. Airplane wheels of the disk type in which metal disks form the sides of the wheel are coming into use. These wheels are unusually well adapted for the fitting of internal brakes and are usually so fitted.

Difference between military and commercial types.—The demand for increased safety in civil airplanes, which has been supported by the requirements of the Department of Commerce, is causing the general introduction of higher grade materials and better workmanship. It is now felt that the materials and general workmanship in the better grade of civil airplanes compare very favorably with those in military airplanes and may be just as good. With the increasing use of engines of larger power, and of several engines, in civil airplanes the value of the product becomes so great, and the demands on it in service so heavy, that the use of the best of materials and workmanship is a true economy.

In spite of the increase in quality of materials and workmanship the civil airplane has been still further differentiated from the military airplane. The chances of successful application of civil types to military uses are correspondingly reduced.

STRUCTURAL MATERIALS—*Metal construction.*—Interest in metal construction has increased markedly. As long as only a few airplanes, usually with individual changes, were being produced by an airplane factory, the use of metal construction was restricted to the simpler parts of the structure where elaborate jigs and fittings were not required. With increasing production of repetition models the expense of special tools becomes justified and the all-metal, or nearly all-metal, airplane may ultimately be cheaper than the part-metal part-wood one.

Specialization in the supply of metal parts, such as wing spars and ribs, is appearing. With the ability to purchase such parts from a parts maker at a less cost than they can be made by the individual airplane builder, an increase in the number of full-metal framed airplanes is sure.

Original designs notable for the ingenuity of the designers containue to appear. The introduction of the Alclad method of protecting duralumin from corrosion has prompted the use of this material in such designs. With reports of practical immunity to corrosion for long periods the drift to other materials has slowed down.

Steel tubing.—Progress has been made in the welding of the corrosion-resisting steels, but as yet tubing of this type is not generally available. There appears no reason to doubt that eventually it will be. In the meantime much attention is being paid to the protection of the inside of steel tubing against corrosion.

Duralumin tubing.—Progress has been made on the application of the Alclad process to duralumin tubing. Until this is accomplished many designers will look with suspicion on duralumin tubing and continue the use of open sections in which the entire surface is accessible.

Floats.—The metal float is rapidly driving the wooden float from the field. Here again the the use of duralumin protected by a coat of pure aluminum has removed one of the main troubles with corrosion. However, floats have been built of nickel, Monel metal, and of stainless steel. A float of the latter material was only slightly heavier than a duralumin float, and the designers believe it can be made as lightly. The recent work of the committee on the loads experienced by the bottoms of airplane floats promises to enable more accurate design of floats.

Rubber protective coatings.—Work on these coatings has continued but progress has been slow. The use of more corrosion-resisting materials which require no coating has drawn attention away from this method of protection.

AIRSHIPS

Technical development and present situation.—With the promise that two large rigid airships will be built in the United States the development of this type of airship has again become active in this country. A second design competition looking toward the procurement of two 6,500,000-cubic foot airships for the Navy Department was held. A contract for the building of two of these airships has been signed and the United States has taken the first steps to resume its one-time position with the leaders in this field.

Experimental investigation and research on the development of improved materials and methods of construction for the new airships have continued. Further methods for the protection of duralumin against corrosion have been developed. A substitute for goldbeater's-skin fabric has been tested in service in the form of a cell in the *Los Angeles*. The results are satisfactory although not perfect. However, succeeding cells will probably be much superior.

In connection with the research on the corrosion of duralumin a large number of samples of girders taken from the *Shenandoah*, either as test members or from the wreckage, have been under observation to determine the rate of progress of corrosion. Recent tests on this material, now more than five years old, have revealed the surprising fact that the strength of the material has remained practically unchanged since the time when the airship was wrecked.

Work with the "Los Angeles".—The continued operation of the *Los Angeles* has demonstrated the skill which has been acquired by the personnel engaged in this work. The airship has made several notable flights, of which the one to Panama and return deserves special mention. On this flight the airship moored to a stub mast at Panama and to the *Patoka* at Guacanayabo Bay, Cuba. Both of these operations were maneuvers largely developed by the personnel connected with the operation of the airship.

In the course of the operation of the *Los Angeles* much information has been gained which has been applied in the design of the new airships for the Navy. Improvements have been made in the water-recovery system to increase its efficiency and methods of producing artificial superheat in the gas have been tried.

Work on the development of improved methods of mooring and handling has continued, and the indications are that these methods can be developed to allow a large reduction in the number of men required.

Metal-clad airship.—The rapid development of intercrystalline corrosion in the duralumin used for the shell plating of this airship led to the substitution of Alclad duralumin 0.010 inch thick in place of the plain duralumin 0.008 inch thick. The hull has been constructed in two sections and is ready to be joined into one. Methods for inflating using carbon dioxide to displace the original air inside the shell and then passing in helium on top of the carbon dioxide as it is drawn out have been tried experimentally with success.

New mooring masts.—No large mooring masts have been built in the United States during the past year. The "stub mast" has been developed to a very successful stage at the naval air station at Lakehurst, N. J. It is now common practice to "take off" directly from this mast, but a flying mooring has not yet been attempted. While the *Los Angeles* has not ridden out any severe weather at this mast, wind shifts of sufficient force to cause the after car to move at a speed of about 5 miles per hour have been experienced.

A mobile stub mast is being erected at Lakehurst and is expected to still further improve the methods of handling airships on the ground.

Helium.—An additional helium tank car using a number of smaller cylinders has been obtained by the Navy Department. The helium storage at Lakehurst has been increased by about 2,500,000 cubic feet by permanently manifolding about 14,000 small cylinders. This use of semiobsolete material has provided an urgently needed increase in storage capacity at a relatively low cost.

Arrangements have been made for the development of a large field of helium-bearing gas near Amarillo, Tex. Pipe lines and a helium production plant are being constructed. It is hoped to demonstrate by this operation what can be done in the way of conservation when practically a whole field is controlled.

The privately owned helium plant is finding no difficulty in disposing of the production beyond that taken by the Government. It has fixed a price for this gas which is only about three times that of hydrogen.

Progress in Great Britain.—The completion of the two large airships building in Great Britain has been delayed and they are not expected to be ready for flight until 1929. Preparations for mooring and handling them on their route to the East are practically complete.

Progress in Germany.—The rigid airship which was under construction in Germany was given the appropriate name of *Graf Zeppelin.* Her recent trip to the United States and return has given renewed impetus to the proposals to apply rigid airships to transoceanic transportation. The voyage was notable for the illustration it gave of the possibility of effecting repairs on an airship while in flight.

This airship is the largest which can be built in the sheds at Friedrichshafen. It is reported that Doctor Eckener believes that larger airships must be used if trans-Atlantic traffic by airship is to be successful. Either larger sheds must be built at Friedrichshafen or any such larger airships must be built elsewhere.

Progress in Spain.—For some time it has been reported that the Spanish Government desired to see an airship line to South America. A company was formed for this purpose and it is now reported that sheds for the construction and docking of the airships of the proposed line are building near Seville.

AIRCRAFT ENGINES

The most notable event in connection with the development of aircraft engines during the past year was undoubtedly the first successful use in repeated flights of an engine using fuel injection and burning heavy oil instead of gasoline. This engine was constructed by the Packard Motor Car Co. It is an air-cooled static radial engine of about 200 horsepower and is reported to weigh about 3 pounds per horsepower.

Aside from the Packard fuel-injection engine no radical developments in the form of unconventional engines have appeared. Air-cooled engines which are suitable for use in military aircraft and which have proved their value, are now available in sizes of 200, 300, 425, 500, and 600 horsepower. The demands for increased performance have led to the provision of higher powers, while the refusal of the military services to accept anything which did not have a maximum of reliability has resulted in the development of remarkable stamina without sacrifice of lightness.

The conspicuous success of the air-cooled radial engine has led many manufacturers to attempt the production of medium-powered engines of that type for commercial use. Although they were faced with new design requirements and in some cases the necessity for long periods of development work in order to produce a conspicuous success was not appreciated, several engines have been produced which have passed the requirements for an approved-type certificate of the Department of Commerce.

The search for a relatively inexpensive substitute for the cheap engines which were available from the war-time stock of engines, which is now nearly exhausted, has led to the rebuilding and adaptation of types which in their original form were not suited for commercial use. The conversion of a water-cooled in-line engine into an air-cooled one or of a rotary radial into a static radial involves serious problems of design and construction, which may be even greater than those involved in a new design. It is not surprising that suitable engines of this character have not appeared in this country.

Operators of aircraft which must keep to fixed schedules, either on mail lines or passenger and mail lines, are fitting engines of higher power than would have been considered necessary a few years ago. The demand that an airplane shall keep to a schedule makes necessary a reserve of power, with its possible additional speed. As a result, many of the higher powered engines originally developed for military airplanes are going into commercial service.

Commercial operators of regular services are also beginning to use fuels of higher qualities, in some cases even superior to the fuels ordinarily used in the military services. This is a further example of how experience in operation leads to and enforces demands for improved measures and better materials to avoid difficulties which have been encountered.

No new types of water-cooled engines were brought out during the past year. Development and improvement in the existing engines have continued. By resorting to higher rotative speeds, higher compressions, and the use of reduction gears, the water-cooled engines have been brought to nearly the same weights per horsepower as air-cooled engines.

Air-cooled radial engines intended for use in both military and commercial aircraft are being developed with reduction gears. The use of reduction gears promises to become general in large multi-engined airplanes, especially in flying boats. These require high propeller thrusts in taking off but can afterward fly at greatly reduced power.

The tendency toward improved aerodynamic form and reduction of parasite resistance in airplanes will probably be strengthened by the results of recent work by the committee on the cowling and cooling of radial air-cooled engines. By the application of one form of cowling a notable increase in performance at the same power has been obtained.

SUMMARY

The year 1928 marked the twenty-fifth anniversary of the first successful flight of an airplane, namely, that made by Orville Wright at Kitty Hawk, N. C., December 17, 1903, in a machine designed and built by Wilbur Wright and Orville Wright. The Government of the United States is formally commemorating this twenty-fifth anniversary of the triumph of the Wright brothers by inviting the nations of the world to attend an international civil aeronautics conference in the city of Washington. On the twenty-fifth anniversary of the first flight there will be a pilgrimage of the delegates and guests of the conference to the scene of the early experiments and of the first flight of the Wright brothers at Kitty Hawk. On this occasion the cornerstone of the national memorial authorized by act of Congress will be laid on the top of Kill Devil Hill, which for four years was used by the Wright brothers in their early flying experiments. On the same occasion there will be unveiled a memorial erected by the National Aeronautic Association to mark the spot near Kill Devil Hill from which the first successful flight of an airplane was made.

Among the demonstrated evidences of the notable progress made during the year 1928 may be mentioned the following: The inauguration in the United States of regular air transport passenger services; the entrance of express companies into the field of aerial express service; the announcement of plans by the Pennsylvania and Santa Fe railroads for a combined air and rail passenger service between the east and west coasts of the United States; an increase of over 100 per cent in the production of airplanes for private ownership and operation; the extension of national airways by the Department of Commerce; the extension of the air mail service; the reduction of air mail postage rates by more than 50 per cent; and the general noticeable improvement in the performance, efficiency, and safety of airplanes. All of these have combined to enable aeronautics to assume an increasingly important rôle in the economic life of the Nation.

The development of the civil and commercial uses of airplanes in the United States has been without the direct subsidies that have characterized European developments, but the Federal Government has nevertheless contributed materially to the development of American aeronautics. The 5-year aircraft building programs of the Army and Navy have served to stabilize the industry. The effective administration of the air commerce act by the Department of Commerce, particularly in the regulation and licensing of aircraft and airmen and in the establishment of lighted airways, including the furnishing of meteorological information by the Weather Bureau, have been important factors. The coordination and prosecution of scientific research on the fundamental problems of flight by the National Advisory Committee for Aeronautics have led to material improvement in the safety and efficiency of airplanes.

The latest important contribution from the committee's laboratories at Langley Field, Va., resulted from a study in the propeller research tunnel of drag and cooling with various forms of cowling for an air-cooled radial engine in a cabin fuselage. By the application of the results of this study to a Curtiss AT-5A Army pursuit training airplane, the maximum speed was increased from 118 to 137 miles per hour. This is equivalent to providing approximately 83 additional horsepower without additional weight or cost of engine, fuel consumption, or weight of structure. This single contribution will repay the cost of the propeller research tunnel many times and fully justifies the committee, not only in having built such a tunnel, but also in recommending as it does that additional funds be provided next year for the construction of a full-scale wind tunnel. Never before in the committee's history or in the history of the development of aeronautics has the value of a new piece of scientific equipment been so well demonstrated.

The development of aviation in America during the past year has been amazing, and emphasizes the necessity for the continued study on a large scale of the basic problems of increase in safety and reduction in cost of construction, maintenance, and operation of aircraft. The research programs of the committee have been enlarged during the past year to serve the increasing needs of a growing industry. Three important new subcommittees have been established—namely, committee on problems of air navigation, committee on aircraft accidents, and committee on aeronautical research in universities. All of the committee's activities are conducted in cooperation with existing agencies, public and private, to the end that the maximum return may be obtained from their use without duplication of effort or loss of time.

The greatest stimulation to the development of aeronautics will come from the education of the public by the private use of airplanes and by the safe operation of commercial air lines. These will come with the solution of the serious and difficult problems of navigating and landing in fog. The development of instruments which will indicate the true position of the aircraft when flying without the assistance of ground vision, and the development of adequate communication systems, are problems now pressing for solution in order that air transport services may be operated with assurance of safety and reliability.

The National Advisory Committee for Aeronautics, as the coordinating agency of the Federal Government for the scientific study of fundamental problems in aeronautics, endeavors to maintain a broad view and wide contact over the whole field of aeronautics without losing sight of the immediate problems of the governmental services. The committee is actively prosecuting investigations which will promote the safety and efficiency of military and civil aircraft. Continuous progress can be assured only by continuous research and experimentation.

CONCLUSION

The manner in which aeronautical progress in the United States has exceeded expectations has been most gratifying. This progress has derived its inspiration and support from many sources. In the main, it is the cumulative result of years of study, research, and experimentation, and the direct relation between notable developments and the preceding scientific studies is clear. Further substantial progress may be expected from the continued prosecution of scientific research. Accordingly, the committee recommends the continuance of the liberal support which has in the past been accorded its work in the fields of pure and applied research on the fundamental problems of flight.

Respectfully submitted.

National Advisory Committee for Aeronautics,
Joseph S. Ames, *Chairman*.